

**Teachers' Guide to
PHYSICS IS FUN
Book Four**

BY JIM JARDINE
PHYSICS IS FUN

An introductory secondary school course

Volume One

Volume Two

Volume Three

Volume Four

TEACHERS' GUIDES TO PHYSICS IS FUN

Teachers' Guide to Physics is Fun Books One and Two

Teachers' Guide to Physics is Fun Book Three

Teachers' Guide to Physics Is Fun Book Four

Teachers' Guide to PHYSICS IS FUN

Book Four

Douglas McMahon

Daniel Stewart's College, Edinburgh

John Hughes

Jordanhill College of Education

Tom Spears

Moray House College of Education



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Preface

The general aim of the *Physics is Fun* series of text books is to stimulate and maintain an interest in physics and to develop an understanding of the basic concepts.

Book Four is the final book of the series. It contains a number of modern topics hitherto not found in school syllabuses at this, the fourth-year stage of an Ordinary Grade course.

The teaching of topics such as oscillations, a.c. circuits, simple electronics and radioactivity at such an elementary level presents a special challenge to the teacher. Expositions which traditionally have been in very mathematical terms have been broken down into simple, qualitative explanations, backed by experiments and demonstrations. Wherever possible, the experiments should be performed by the pupils; they should be 'pupil's experiences' rather than teacher's.

The order of presentation in Chapters 8 and 9 differs from that in Circular 490 (Revised) of the Scottish Education Department: Alternative Physics. In these chapters, a.c. circuits are treated first. This enables one to proceed directly from considerations of mechanical oscillations to that of electrical oscillations and thus to a more obvious analogy between the two.

The material of Chapter 12, 'Rays of Activity', can be taught more expeditiously by using a d.c. amplifier rather than by the use of a pulse electroscope.

No two schools can be expected to have identical apparatus and no two teachers have the same idea of what practical work should be performed. For this reason, the text book contains many more experiments and demonstrations than could be completed in the usual time allocated to physics. Accordingly, from time to time, a selection of practical work has been suggested.

It is particularly difficult to give even a rough time table because only two terms are available before the S.C.E. exam. However, the following, based on a total of thirty weeks, gives some idea of the relative amounts of time suggested for different sections of the course, and may be of some assistance.

Chapters 1 and 2: 4 weeks
Chapters 3, 4 and 5: 9 weeks
Chapters 6 and 7: 4 weeks
Chapters 8 and 9: 8 weeks
Chapters 10, 11, 12 and 13: 5 weeks

The chapters in the Guide are numbered to correspond to those in the text book. Each contains notes on the experiments and demonstrations, and answers to the numbered questions. In many cases the answers are more detailed than one could reasonably expect from a fourth-year pupil.

Pupils should not have access to this Guide. To allow them such access would be to defeat one of the main purposes of the course.

I The Electron (pp. 1-16)

Introduction

Some of the properties of the electron are 'discovered' in Demonstrations 1.1 and 1.2 using apparatus similar to that used in the original investigations. There is a certain amount of duplication, but both are worth doing, not only for the information gained about the electron, but also for the revision involved in the techniques used.

The investigation of electric fields in Experiment 1.3 and the chance to restate the idea that magnetic fields are due to electricity (or charged particles) in motion, while electric fields are due to electricity at rest, is necessary. There is, however, no need to use all the methods suggested; the first is the most important.

Demonstrations 1.4, 1.5 and 1.6 all lead up to Millikan's experiment. Obviously 1.4 and the macro-Millikan apparatus mentioned at the end of 1.5 are very similar and one or other will serve the purpose. A selection from the others could be made.

The discovery that there is a basic unit of charge is so important that time must be spent in studying the static version of Millikan's experiment and attempting problems associated with it.

Demonstration 1.7 would only be performed if time were plentiful.

Experimental Work

Demonstration 1.1. (i) The hot cathode emits light which casts a sharp shadow of the cross on the end of the tube. This indicates that the light rays have travelled in straight lines.

(ii) When the E.H.T. voltage is high enough, a sharp 'cathode ray shadow' appears, the screen glowing outside the shadow of the cross. This shadow is approximately the same size as that cast by the light rays, indicating that the cathode rays travel in the same straight lines as the light rays.

(iii) (a) The light shadow does not move.

(b) The cathode ray shadow moves to the right or left depending on which pole of the magnet is nearer the tube. This suggests that cathode rays and light are not similar phenomena.

Application of the rule mentioned leads to the conclusion that the cathode rays are deflected in the same direction as electrons would be deflected if they were travelling from the cathode to the cross.

(iv) The microammeter indicates that electrons are flowing from A to B. This suggests a flow of negative charge in the tube towards the cross and so supports the findings in (iii).

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When the p.d. is high enough to give a clear shadow, the current may be more than 500 microamps. With the Teltron apparatus, a 1 mA f.s.d. meter may be required.

When the wire is disconnected from the cross, the cathode ray shadow becomes larger. Discussion of this leads to further confirmation of the negative charge on the rays and indication that the effect may be due to particles rather than waves.

The shadow becomes larger due to the collection of negative charge by the cross, which will then tend to repel electrons causing the already diverging beam to spread out further.

Demonstration 1.2. (a) When the E.H.T. supply is increased to about 2 kV a fine blue line appears on the screen. Electrons striking the fluorescent material, used to coat the screen, raise electrons in this material to a higher than normal energy level. They return to their ground state, emitting light as they do so.

(i) An Alnico or similar type of bar magnet will do. If it is held end on to the tube so that it is approximately at right angles to the screen, the beam is deflected up or down. Reversal of the magnet leads to reversal of the deflection. Variation of the distance between the magnet and the tube affects the amount of deflection.

(ii) The deflection is not large. In order to make it obvious, the charged rod should be held in contact with or very near the tube, at the point where the cylindrical part meets the bulb. The beam is deflected away from the rod.

When the current through the coils is switched on and adjusted, the beam is deflected up or down depending on the field direction. Take care to connect the coils so that their inner faces are unlike poles; then the field lines passing through the tube are approximately horizontal.

6 V may be obtained from accumulators, car battery, or some special unit, but it is, in fact, much more than enough to produce a reasonable deflection. 2 V from a single accumulator is sufficient.

When the electric field is applied (note that, as described in the text, this may be taken from the E.H.T. unit being used to accelerate the electrons) with the upper plate negative, the beam is deflected downwards. The path looks similar to that expected for a stone projected horizontally. It is a parabola.

Just as the stone would be in a uniform gravitational field, the electrons are in a uniform electric field. The stone would have mass and momentum, and this suggests that electrons have mass and momentum too. Also, from the direction of deflection, they carry a negative charge.

The greater the p.d. between the plates, the greater the deflection of the beam.

Reversal of the field leads to the beam being deflected upwards.

When the accelerating voltage is reduced, the electrons travel more slowly, take more time to pass through the deflecting field, and are deflected further. The curvature of the beam is seen to increase.

The fields can be used to produce no resultant deflection of the beam. If the top plate is negative, producing a downward deflection, the magnetic field must be directed towards the observer.

(b) No additional comment is necessary.

Experiment 1.3. (a) Carbon tetrachloride is probably the most suitable of the liquids. Grass seeds or semolina, in *small* quantities, have been found to be most satisfactory; iron filings tend to sink; paraffin oil with graphite works quite well.

The fields are produced by

oppositely charged
parallel plates,
e.g. of copper.

oppositely charged
rods, e.g. of
carbon.

a single charged rod
encircled by an oppositely charged
ring, e.g. of copper foil.

Oppositely charged
parallel plates,
closer than above.

a plate and rod,
oppositely charged.

(b) The threads may be attached by Sellotape.

(c) The piece of foil, having had charge redistributed on it by induction, is attracted towards the charged body which is creating the field, and so the straw lies along a field line.

An alternative and simpler pivot for the straw is a large pin (such as is used in optics experiments) pushed through the straw at the centre of mass of straw plus foil. It works satisfactorily.

Demonstration 1.4. The nylon threads and their support rod (polythene is suitable) lie in a plane parallel to the plates so that the sphere can move only at right angles to the plates.

The force on the sphere is greatest when the plates are close together; about 7 cm is suitable.

A graphite-coated polystyrene sphere such as is supplied with macro-Millikan apparatus is a suitable alternative to the polythene sphere.

The charge may be easily put on the sphere by induction, using a charged polythene rod.

(i) The greater the p.d., the greater the displacement.

(ii) The greater the charge, the greater the displacement.

The similar sphere must be insulated. Attaching it with Sellotape to the end of an uncharged polythene rod has been found to be satisfactory. The suspended sphere must be lifted from between the plates while charge is being shared, otherwise it is almost certain to be forced against one or other of the plates.

(a) If the p.d. between the plates is increased, the force on the sphere is *increased*.

(b) If the charge on the sphere is increased, the force on the sphere is *increased*.

Demonstration 1.5. (i) The straws stand upright. If the field strength is varied, they can be made to jump up and down.

(ii) When the p.d. is strong enough, it jumps up and down between the plates. It initially receives charge from the bottom plate on which it is resting, is attracted to the top plate, receives charge there so that its original charge is reversed, is repelled, etc.

(iii) When the cylinder is balanced, the equal and opposite forces acting on it are gravity and the force due to the electric field.

The apparatus shown in Fig. 11 can also be used in parts (i) and (ii) above. Its only minor drawback is that it does not contain the straws or polystyrene balls, the latter in particular tending to escape rapidly!

Demonstration 1.6. (i) When the supply is switched off, all the grains move down (a form of projection may be used in which the image is inverted, in which case all the grains will appear to rise). This is because the only force acting, apart from fluid friction, is gravity.

The grains do not have the same speed.

The speed of each drop appears to be constant, each reaching a steady terminal speed quickly.

(ii) The grains will have fallen to the bottom of the box. When the p.d. is applied they all rise, showing that there is a force on them due to the field and therefore that they are charged. They become charged by contact with the bottom electrode. As they do not all receive the same charge, some having a greater capacity than others, they do not experience the same force and so they do not move with the same speed.

When the p.d. between the plates is altered, the electrostatic force on each grain changes and so its speed changes.

(iii) This is not particularly easy to do, but even if the grain is not brought to rest for any length of time, slight changes in p.d. can at least make it move up and down about a mean position.

The forces acting when the grain is at rest are gravity vertically down, and the electrostatic force vertically up. They are balanced. If the charge were suddenly altered, the electrostatic force would

change and the forces would no longer balance; the grain would move.

(iv) The direction of motion of most of the grains is reversed, indicating that the grains moving up had one sign of charge and those moving down had the other, the direction of the force on each being reversed when the field is reversed.

There is an exception. Some grains are repelled by the lower plate, but, as they come slowly towards the top plate, they stop and then start falling. When the field is reversed they fall faster.

This whole demonstration is very effective. It is essential to have the box well filled with liquid paraffin, leaving no air bubbles, and to use a few grains of sand only.

Demonstration 1.7. As the current through the coils is increased, the the shadow becomes smaller and rotates, the direction of rotation depending on the direction of the field. The field is parallel to the axis of the tube and most of the electrons will have a velocity component at right angles to the axis as they tend to spread out, virtually from a point, due to mutual repulsion. There is therefore on each electron a force which changes its velocity. It is caused to spiral about the field lines. This makes the electrons bend round the cross and produce a smaller tilted shadow.

For a given field strength, increase in anode voltage makes the electrons move faster. Their increased momentum makes them less easily deflected by the field and so the shadow becomes larger. At no time is it larger than when no field is applied by the coils.

ANSWERS TO QUESTIONS

1. The rays possess energy.

2. When the dome is earthed, the potential difference between it and the belt is fixed. A constant amount of energy is required to transfer equal charges from belt to dome.

When the dome is not earthed, its potential rises as charge is transferred to it and so more energy is needed to transfer successive equal charges from belt to dome. The motor finds this more difficult, slows down, and may eventually stop.

3. The particle will experience a constant force directed towards A. It will therefore be accelerated towards A and will have kinetic energy there.

The work done on it in moving it from B to A = QV .

Therefore the K.E., $\frac{1}{2}mv^2 = QV$.

Therefore $v = \sqrt{\left(\frac{2QV}{m}\right)}$.

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4. If the electron has charge e coulombs, it will gain energy of $100e$ joules in being accelerated through 100 volts.

$$\begin{aligned}\frac{1}{2}mv^2 &= 100e & v^2 &= 2 \times \frac{100e}{m} \\ & & &= 2 \times 100 \times 1.76 \times 10^{11} \\ & & &= 35.2 \times 10^{12} \\ & & v &= 6 \times 10^6 \text{ m/s (approx.).}\end{aligned}$$

5. The new force due to the electric field has replaced the frictional force due to the air.

6. The masses fall into five groups: approximately 26, 39, 52, 65, and 78 g, i.e. in regular steps, indicating that there is a definite number of articles in each bag, e.g. 2, 3, 4, 5 and 6.

Marbles are more likely than marmalade.

7. Values of charge are approximately 3.2, 4.8, 6.4, 8.0, 9.6, 11.2, 12.8, 14.4 and 16×10^{-19} coulombs.

Graphing, as in 6, will help to emphasise the pattern.

8. Each is a multiple of 1.6×10^{-19} coulombs which is likely to be the smallest charge.

9. Were there a smaller charge, values between those quoted in question 7 would have been expected.

10. $e/m = 1.76 \times 10^{11}$ C/kg

$$m = \frac{e}{1.76 \times 10^{11}} = \frac{1.6 \times 10^{-19}}{1.76 \times 10^{11}} = 9.1 \times 10^{-31} \text{ kg.}$$

This supports J. J. Thomson's hunch (p. 5) that the mass of the electron is very much less than the mass of the hydrogen atom.

11. A solution is possible if it is assumed that the original speed of the electron is zero.

Gain in K.E. = work done by the field.

$\frac{1}{2}mv^2 = eV$, where v is the final speed of the electron.

$$\therefore v^2 = \frac{2eV}{m} = \frac{2 \times 1.6 \times 10^{-19} \times 500}{9.1 \times 10^{-31}}$$

$$\therefore v = 1.3 \times 10^7 \text{ m/s.}$$

$$12. \text{ Number of electrons} = \frac{1}{1.6 \times 10^{-19}} = 6.25 \times 10^{18}$$

$$1 \text{ A} = 1 \text{ coulomb/second} = 6.25 \times 10^{18} \text{ electrons/s.}$$

$$13. 0.1 \mu\text{C} = 10^{-7} \text{ C}$$

$$= 6.25 \times 10^{18} \times 10^{-7} \text{ electrons}$$

$$= 6.25 \times 10^{11} \text{ electrons.}$$

14. Between A and B, the electrons will be accelerating towards B. There is no p.d. between B and D and so the electrons will travel with constant velocity in that region.

Between D and E, they will be subject to a constant upward force which will produce an upward acceleration but will leave the horizontal velocity constant.

$$15. \text{ Force on electron} = \mathcal{E} Q = 400 \times 1.6 \times 10^{-19} \\ = 6.4 \times 10^{-17} \text{ N.}$$

$$F = ma \quad a = \frac{F}{m} = \frac{6.4 \times 10^{-17}}{9.1 \times 10^{-31}} \\ = 7 \times 10^{13} \text{ m/s}^2.$$

In the gravitational field $a = 10 \text{ m/s}^2$.

$$\therefore 16. F = 10^5 \times 1.6 \times 10^{-19} \text{ N} \\ = 1.6 \times 10^{-14} \text{ N.}$$

As the drop is in equilibrium, this force is equal in size to the weight of the drop.

$$mg = 1.6 \times 10^{-14}$$

$$\text{Taking } g = 10 \text{ m/s}^2, m = 1.6 \times 10^{-15} \text{ kg.}$$

$$17. (i) \mathcal{E} = \frac{100}{5} = 20 \text{ V/cm} = 2 \times 10^3 \text{ V/m.}$$

$$(ii) \text{ K.E.} = \text{Work done in raising it to the top plate} \\ = VQ = 100 \times 30 \times 10^{-6} = 3 \times 10^{-3} \text{ J.}$$

$$(iii) \frac{1}{2}mv^2 = 3 \times 10^{-3} \\ v^2 = \frac{2 \times 3 \times 10^{-3}}{3 \times 10^{-12}} = 20 \times 10^8. \\ v = 4.5 \times 10^4 \text{ m/s.}$$

$$(iv) \text{ Potential gradient} = 2 \times 10^3 \text{ V/m}$$

$$\text{Field intensity} = 2 \times 10^3 \text{ N/C}$$

$$\text{Force on the charge} = 2 \times 10^3 \times 30 \times 10^{-6} \\ = 6 \times 10^{-2} \text{ N.}$$

$$18. \text{ Force of gravity} = mg = 1.6 \times 10^{-15} \times 10 \text{ N} \\ = 1.6 \times 10^{-14} \text{ N.}$$

$$\text{Force needed to balance drop} = 1.6 \times 10^{-14} \text{ N.}$$

$$\text{To balance drop, potential gradient} = \frac{200}{10^{-2}} \\ = 2 \times 10^4 \text{ V/m.}$$

$$\text{Field intensity} = 2 \times 10^4 \text{ N/C.}$$

$$\text{Charge on drop} = \frac{1.6 \times 10^{-14}}{2 \times 10^4} = 8 \times 10^{-19} \text{ C.}$$

$$\text{Charge of electron} = 1.6 \times 10^{-19} \text{ C.}$$

Drop carries five electronic charges.

$$19. \text{ Kinetic energy of electron} = \frac{1}{2}mv^2 \\ = \frac{1}{2} \times 9.1 \times 10^{-31} \times 10^{12} \text{ J} \\ = 4.55 \times 10^{-19} \text{ J} \\ = \frac{4.55 \times 10^{-19}}{1.6 \times 10^{-19}} \text{ eV} \\ = 2.8 \text{ eV (approx.).}$$

This is about ninety times the average K.E. of an air molecule at room temperature.

2 Electrons at Rest (pp. 17-23)

Introduction

As the electroscope is the most convenient instrument for measuring p.d. in the experiments which follow, Experiment 2.1 and Demonstration 2.2 are used to establish the fact that it does indicate p.d. rather than charge. The first of these will take pupil very little time to do, and the second can be demonstrated quickly; neither should be omitted.

Experiments 2.3 and 2.4 show that when two bodies are charged by contact, charge is conserved. The latter is neater.

That charge is conserved when charged particles are moved from one body to another is established in Experiment 2.5.

The distribution of charge on a conductor, particularly a hollow one and a pointed one, are investigated in the next six experiments and demonstrations, of which 2.7 is probably the least important. 2.8 and 2.9 are possibly more of a Higher than an Ordinary standard.

Capacitors are studied through the remaining Experiments and Demonstrations, of which 2.13, 2.19 and 2.22 (which is very similar to 2.7), would be the first to be omitted if time were short.

Experimental Work

Experiment 2.1. The leaf is not deflected, suggesting that the electroscope indicates p.d. and not charge.

Demonstration 2.2. The deflection of the leaf does vary with the applied voltage, increasing as the voltage increases. Some E.H.T. units have a voltmeter incorporated. This may be used in place of the moving coil meter illustrated. If a separate meter is used, it must have a very high resistance.

When calibrated, the electroscope is called an electrometer.

Experiment 2.3. (i) The rod may be tested to show that it has been discharged by bringing it up to an uncharged electroscope, and moving the whole length of it past and close to the plate, or by inserting each end, in turn, into a can placed on the plate of an uncharged electroscope. There will be no deflection of the leaf.

When the rod is withdrawn, the leaf is deflected; the duster has been charged. The rod is found to be charged also. When the rod is replaced, the leaf deflection becomes zero, indicating that rod and duster had had equal and opposite charges.

The duster should neither be too tight a fit, otherwise it will accompany the rod when the latter is removed from the can, nor too slack, otherwise insufficient contact will lead to a very small charge being transferred between cloth and rod.

(ii) The cellulose acetate rod can charge the duster, although not as easily as the polythene can.

Electrons are more easily *removed* from acetate.

Polythene normally *takes* electrons from other substances.

It is usually easier for polythene to gain electrons than for acetate to lose them.

Experiment 2.4. (a) Each causes a deflection of the leaf, showing that each is charged.

(b) There is no deflection, showing that the charges on the rods were equal and opposite.

To test the polarity of the rods, charge an electroscope so that the deflection is about 45° . Bring up the rods in turn. One will produce an increased deflection and the other a decreased deflection, showing that they have different polarity.

It is most satisfactory to rub the ends of the rods together and then to insert these ends into the can.

Experiment 2.5. (a) Test for discharge as described in Experiment 2.3 (i). Separate the spheres while they are near the generator. On testing (for method, see 2.4 (b)) each is found to be charged, but with opposite polarity. In the situation shown A will be negative and B positive.

In the field of the generator, some electrons will be attracted from B to A, making A negative and B positive. When they are separated they retain these charges. If they were separated after being taken well away from the generator, the electrons would have moved back to B and the spheres would be uncharged when separated.

Suitable spheres, diameter $1\frac{1}{4}$ inches, with holes in them, can be obtained from Griffin and George. Polythene rods can be cut up to make satisfactory handles.

(b) This is just as satisfactory.

Experiment 2.6. (i) When the sphere is removed the leaf collapses. The sphere is still charged (test by lowering it into can on plate of another uncharged electroscope). When the sphere touches the bottom of the can there is no change in the deflection of the leaf. When removed and tested, the sphere is found to be discharged.

Consider Fig. 30. When the charged sphere is inside the can, it induces a negative charge on the inside of the can and an equal positive charge on the outside. The plate and leaf system of the electroscope is, in effect, part of the outside of the can. The fact that

the deflection is not changed when the sphere is allowed to touch the bottom of the can shows that the charge on the outside of the can has not been affected. There has been no flow of charge to or from it. Therefore the negative charge on the inside of the can must have been equal in size to the positive charge on the sphere.

Touching the two together leads to electrons flowing from the inside of the can to the sphere so that neither has any charge, confirmed by finding that the sphere has lost all its charge. Therefore the positive charge on the outside of the can is equal to the positive charge that was on the sphere. Thus the sphere induced charges equal in size to its own charge on the inside and outside of the can.

(ii) The sphere is found to have retained some of its charge. The can is charged too.

(iii) There is no charge on the inside of the can, but there is charge on the outside, confirming the findings of (i) and (ii).

Summing up. There is no net or resultant charge on the inside of a hollow conductor. If there are charged bodies inside it, their total charge, taking account of sign, is equal and opposite to the charge induced on the inside surface of the can. If there are no charged bodies inside it, there is no charge on the inside surface.

Experiment 2.7. The larger sphere produces the bigger deflection, indicating that it had produced a higher p.d. across the electroscope and had therefore given a greater charge to it. This shows that when two spheres share charge, the one with the larger radius gets the bigger share of the charge (it has greater capacitance).

Griffin and George spheres of diameter $\frac{1}{2}$ and $\frac{3}{4}$ inch can be used to augment the supply of $1\frac{1}{4}$ inch diameter spheres recommended in 2.5 (a).

The initial charging may be done by induction using a polythene rod.

Demonstration 2.8. (i) The electroscope can be charged easily.

(ii) If the connections are as in Fig. 32, the electroscope *can* be charged, though not so readily. Consider the sphere in contact with the plate of the electroscope. The positive charge on the case of the electroscope induces a negative charge on the leaf and its support, and a positive charge on the plate and sphere. When the positively charged sphere is removed and touched on to the bottom of the can, it is discharged. The electroscope is left with a small negative charge.

Repetition causes more charge to be transferred; the electroscope becomes more and more negatively charged and so the deflection of the leaf increases.

This, of course, is not what the demonstration is intended to show.

To produce the required results, earth the case of the electroscope, as indicated in the 1968 reprint of Book Four (the earth socket on the E.H.T. unit is convenient). Then in (i), the electroscope will be charged, and in (ii) it will not be charged.

Demonstration 2.9. (i) A p.d. greater than the E.H.T. voltage as indicated by the meter on the unit cannot be obtained.

Suppose the case of the electroscope is connected to the E.H.T. positive terminal. They will be at the same potential. The leaf will obtain a negative charge and the can a positive charge by induction. The leaf and can will be at the same positive potential, somewhat less than that of the case.

The sphere, at the same negative potential as the E.H.T. negative terminal, receives negative charge. When it is moved to touch the outside of the can, some electrons flow from it to the can, making the potential of the can less positive. Repetition leads to the transfer of more electrons, a smaller number each time as the can's potential becomes less positive and then more negative. Eventually the potential of the can is the same as that of the negative terminal of the supply and so when the sphere touches the can, they are at the same potential and no current flows. The p.d. across the electroscope is then equal to that of the supply.

(ii) A p.d. greater than that of the supply *can* be obtained. A large number of transfers may be needed. In this case, all the charge flows from the sphere to the can regardless of the potential of the can.

The extra energy comes from the person doing the charging. Each time he brings the charged conductor towards the can he has to do work against the field (the can and conductor have the same kind of charge).

In the Van de Graaff generator charge is transferred to the outside of the sphere via the inside and a very high potential difference with respect to earth is produced.

Experiment 2.10. In each case it is found that the charge density is greatest at those parts of the surface which are most convex, i.e. at the edge of the electrophorus plate or the charged can and at the pointed end of the pear-shaped body.

Each time, before the proof plane is moved from the charged body to the can, the electroscope must be discharged. The proof plane should be touched on to the bottom of the can.

Any small insulated conductor, with no sharp edges, can be used as a proof plane.

Experiment 2.11. (i) The p.d. between the conductor and earth is the same for all points on the conductor. There is no p.d. between points on it.

The conductor should not have too high a charge otherwise too high an initial deflection of the leaf will be produced, with no chance to detect an increase.

(ii) There is no p.d.

Demonstration 2.12. The energy was stored in the glass of the jar.

The inner cup can be lifted out safely by using a polythene rod under the hook.

Project 2.13. The comb must be insulated from everything except the foil to which it is attached. The points of the comb should be as near as possible to the disc without touching it.

Experiment 2.14. (i) To ensure that all the charge from the electrophorus has been transferred, it should be touched on to the foil inside the tumbler, as near the bottom as possible.

(ii) The same deflection is produced by a smaller number of 'strokes', showing that this capacitor has the smaller capacitance.

In each case, make sure that the foil is made as smooth as possible; ridges and edges lead to loss of charge. Contact with the inner surface can be made by winding wire (bare copper wire is suitable) round the outside and tightening it to fit, then moving it to the inside where it can easily be wedged in. Good contact with the outside can be ensured by using bare copper wire in the same way.

The electrophorus plate may be too large to go into the capacitor. Any small insulated body, such as the brass sphere on its polythene handle used in earlier experiments, can be used as a charger.

The number of strokes required will vary greatly, depending on the charge on the base of the electrophorus, on the plate or sphere used, on the size of tumbler, etc., but it has been found that, as expected, the number of strokes required to charge the smaller capacitor to a certain p.d. is about half that required to charge the larger.

Demonstration 2.15. (i) Typical results, inserting the deflection angle:

Charge Q (strokes)	Deflection angle	p.d. V volts	Q/V
4	10°	330	0.012
7	20°	620	0.011
11	30°	990	0.011
15	40°	1,480	0.010
20	50°	1,900	0.011

Q is directly proportional to V .

The graph is a straight line passing through the origin (approx.).

(ii) Similar results are obtained, Q/V being about half the value found in (i).

An alternative method is to record the deflections, by marking the screen, for 4, 8, 12, 16, etc. strokes, and then finding the p.d.'s which give corresponding deflections.

Experiment 2.16. When two capacitors are stacked in series, the number of strokes required is approximately half the number required to charge a single capacitor. When three capacitors are stacked, about one third the number of strokes are required.

Thus the capacitance of two similar capacitors in series is half that of one, and the capacitance of three is one third that of one.

When two capacitors are connected in parallel, about twice the number of strokes are needed and when three are in parallel, about three times the number of strokes are needed. Great patience and stamina are also needed! This is clearly a pupil experiment.

The capacitance of similar capacitors in parallel is the sum of their capacitances.

Experiment 2.17. (i) The leaf rises indicating that the p.d. has increased and therefore that the capacitance has decreased.

(ii) As the plates are separated, the leaf rises; as they are brought together, the leaf falls. Thus, as the separation increases, the p.d. becomes greater because the capacitance has become less.

(iii) As each insulating slab is introduced, the leaf falls; the p.d. has decreased because the capacitance has increased.

Ordinary aluminium foil, folded a few times to give it rigidity, and Sellotaped on to polythene rods, can be used.

Capacitance increases when the area of overlap *increases*.

Capacitance increases when the plates are moved *closer*.

Capacitance increases when the plates are moved *together*.

Capacitance *increases* when a dielectric is introduced.

Demonstration 2.18. (i) When the switch is moved to the charge position, the bulb lights momentarily. Charge must have flowed through the capacitor. When the switch is moved to the discharge position, the bulb again lights momentarily.

During charging, the p.d. across the capacitor rises to 9 V and, as the current flows, the bulb lights. When the switch is moved over there is a 9 V p.d. across the capacitor which makes current flow through the bulb, the p.d. dropping fairly quickly to zero because the resistance of the bulb is not very high.

(ii) The bulb does not light. While the capacitor is being charged, electrons flow to the top plate in the figure, making it negative.

When the capacitor is fully charged, the p.d. across it is 9 V and acts against the battery p.d. The resultant p.d. in the circuit is zero.

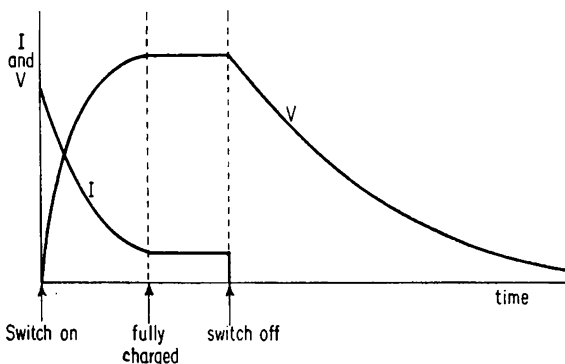
Disconnecting and then reconnecting the battery produces no change in the situation.

Experiment 2.19. (a) Electric energy stored in the capacitor produces heat and light in the bulb.

(b) In this case, mechanical energy is produced and, incidentally, some sound and heat.

Demonstration 2.20. (a) Neither meter can be said to read first, but the ammeter reading rises quickly from zero, whereas the voltmeter rise is slow. The voltmeter does not read 9 V immediately because the capacitor has a large capacitance and the rest of the circuit has a large resistance, these combining to produce a relatively long charging time for the capacitor. When the capacitor is fully charged the p.d. across it is 9 V.

When the switch is opened, the capacitor discharges through the voltmeter. As the latter has a much higher resistance than the charging circuit (a typical value is 100 kilohms), the discharge time is longer.



The ammeter reading is not zero when the capacitor is fully charged because a steady current passes through the voltmeter. When the switch is opened, the current through the ammeter drops to zero immediately.

(b) The ammeter is now in the discharging circuit and current passes through it in the opposite direction to that during charging.

Demonstration 2.21. (i) When the power unit is switched off, the charge on the capacitor (and the electroscope) remains constant. There is no indication of current flow on the galvanometer and the leaf deflection is unchanged.

(ii) As the capacitance is increased or decreased, the leaf deflection does not change, showing that the p.d. across the capacitor (set by the supply) has not changed.

(iii) As the capacitance is being increased, there is a current pulse indicated, the direction of the current being the same as when the capacitor was first charged. More charge has flowed to the capacitor. The leaf deflection does not change.

Consider $Q = VC$. V is unchanged and so the charge on the capacitor increases as the capacitance increases. When the capacitance is decreased, charge flows from the capacitor, the galvoamplifier indicating a pulse in the opposite direction to that during charging. The p.d. is unchanged.

(iv) While the capacitance is being increased, a little charge flows to it from the electroscope; the leaf falls gradually. While the capacitance is being decreased, some charge flows from the capacitor to the electroscope producing a gradual increase in deflection. The total charge on capacitor plus electroscope is constant.

Consider $Q = VC$. The capacitance of the capacitor is much greater than that of the electroscope and so the quantity of charge which flows to or from the capacitor is small. Thus, as Q is approximately constant, an increase in C must lead to a decrease in V , and a decrease in C to an increase in V .

A Pye Scalamp Galvanometer (Model 7891/5), and others similar, may be used. They give a small but definite deflection.

Demonstration 2.22. To ensure that both spheres are at the same potential, one may be charged by contact with the generator and then touched against the other. When they are discharged in turn through the galvanometer, it is found that the larger sphere has the greater charge.

The two spheres must be well insulated. If the generator has an auxiliary sphere to which sparks are usually made to pass, it may be used as one of the spheres. Alternatively, two brass spheres of different sizes, each on a polythene handle, may be used.

This can be a fairly tricky experiment to carry out, because the Van de Graaff sphere may not hold its charge for any great length of time after switching off. The generator must be in good order if chances of success are to be high. It has been found that running the generator motor at low speed, switching off and then quickly making contact between the sphere and the galvo (the other terminal of which is connected to earth) leads to an easily seen 'kick' of the spot. It is best to start with the galvo sensitivity low and to gradually increase it until the kick is appreciable.

Good results can be obtained by using an electrophorus instead of the Van de Graaff. Plates or spheres of different sizes can be compared. The conductors will not receive as high a charge as they

would from the generator, but it has been found to be high enough to produce easily compared kicks on a ballistic galvo set at high sensitivity.

ANSWERS TO QUESTIONS

1. Yes, it can be used to measure an alternating voltage. Consider an instant when the direction of the voltage is such that the leaf is positive and the case is negative. The leaf will be deflected. When the direction of the voltage is reversed so that the leaf becomes negative and the case positive, the leaf will still be deflected.

Unless the frequency of the voltage is very low, the inertia of the leaf will prevent it following the variation in the size of the voltage. It will maintain a steady deflection which will be a measure of the voltage.

2. The bird becomes charged. As the same kind of charge will be on each feather, there will be mutual repulsion and the feathers will spread out.

The bird will not receive an electric shock because it is not connected to a point between which and the wire there is a large potential difference, in particular the earth.

3. The metal rod can be charged. If the rod is held in the hand the charge will escape to earth via the body, or, if the person holding the rod is insulated from earth, the body will take such a large share of the charge that what remains on the rod will be negligible. The rod must therefore be insulated while rubbed, e.g. by holding it between polythene sheets (an assistant is required!), or attaching it with Sellotape to a polythene rod or a cellulose acetate strip.

The rod should be tested for charge using an electroscope in the usual way.

4. This is easily done. The polythene rod is more effective than the expanded polystyrene. A cellulose acetate strip is also effective.

Contact between metal and insulator allows electrons to move from one to the other, leaving both charged.

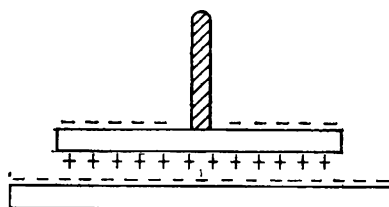
5. Balance one rod on an upturned watch glass or on two such glasses put together to make a converging lens shape (a lens itself is more costly to replace if broken) and bring one end of the other rod up to one end of it. The balanced rod will be repelled.

6. Balance a charged cellulose acetate rod as in question 5, and bring up a charged polythene rod to one end of it. The balanced rod will be attracted.

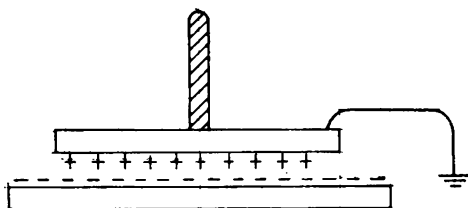
7. No.

8. Yes. If an originally uncharged body is brought near either rod, induced charge on it will lead to mutual attraction.

9.



When the plate is laid on the slab, the actual area of contact is very small (see Book Two, p. 22) and, as polythene is a good insulator, very little charge flows to the plate. Charges will be induced as shown above.



When the plate is earthed by touching it momentarily the negative charge escapes to earth. The plate is left with a positive charge which may be transferred to any desired place.

10. The electroscope is earthed momentarily while the charged polythene rod is held near the plate. When the rod is removed the electroscope is left with a positive charge.

When a positively charged object is brought close to the plate of a negatively charged electroscope, some electrons are attracted from the leaf to the plate, leaving the leaf less negatively charged. Its deflection will decrease.

N.B. If the positive charge on the object is sufficiently large, so many electrons may be removed from leaf to plate that the former becomes positively charged. In this case the leaf will fall and then rise again, its final position possibly being higher than its original. Care must be taken lest the charged object is brought up so quickly that only the end effect is seen and the wrong inference made.

If the object brought up has a negative charge, some electrons are repelled from plate to leaf, making the latter more negative and its position consequently higher.

If the leaf falls when an object is brought near the plate of a positively charged electroscope, then the object is either negatively charged or uncharged. Consider an uncharged body. When it is brought near the plate of the electroscope, charge is induced on it.

This induced charge in turn causes a movement of charge in the electroscope which causes the leaf deflection to decrease. The effect is most pronounced when the object is earthed. In this case the charge which would have been on the side far from the electroscope and would have been of the same sign as that on the electroscope will be removed to earth and so will not tend to reduce the effect of the charge induced on the near side of the object.

11. One terminal of the battery should be connected momentarily to the plate, and the other to the case, of an electroscope. A deflection will be produced. (If this is being demonstrated, a low-capacity electroscope should be used—projection will probably be necessary.) If a charged polythene rod (negative) is now brought near the plate, a decrease in deflection will indicate that the plate is positive and an increase that it is negative.

12. The boy had been charged by induction; there being little contact area between the glass rod and the shoe soles, and both being poor conductors, there would be negligible charge transfer.

The glass rod will be positively charged. Electrons will be attracted towards it, making the boy's feet negative and his head positive. By induction, each bit of paper will become negative on the side nearer the boy and will be attracted.

Presumably the experiment was made more effective by the concentration of induced charge on the boy's rather pointed nose!

13. When the sphere is first lowered into the can the leaf rises. Equal and opposite charges are induced on the inside of the can, the plate and leaf of the electroscope being effectively part of the outside. When the can is earthed temporarily, the leaf drops because the charge on the outside of the can has been removed.

When the sphere is removed, the charge which had been held on the inside of the can moves to the outside and the leaf rises. The deflection will be the same as the original one shown in Fig. 30.

14. Charge is shared between the charged conductor and the earth. The latter has such a large capacity that its share of the charge is infinitely greater than that of the conductor, which effectively loses all its charge.

If the conductor is positively charged, electrons flow from earth to it; if it is negatively charged, electrons flow from it to earth.

15. When the plate of the electrophorus is resting on the slab, there is a force of attraction between them due to the induced charge on the plate. Work must be done to lift the plate from the slab. Thus the operator is the energy source. As the plate is raised it gains electrical potential energy.

16. If the electrophorus plate, having been charged in the usual way, is brought up to the electroscope so that there is a small gap between the needle and the electroscope plate, ionisation of air molecules in the strong field near the point of the needle leads to a

flow of ions to the needle and to the plate. If the electrophorus slab were positively charged, its plate and the needle would be negatively charged; negative ions would flow to the electroscope giving it a negative charge.

N.B. The common electrophorus slab (of polythene or ebonite) acquires a negative charge when rubbed. The plate would then become positively charged.

17. Attach the needle to the plate of one electroscope using Sellotape. If the negatively charged rod is brought near the point, ionisation will lead to positive ions flowing to the rod and negative ions to the electroscope. Thus the latter becomes negatively charged.

The other electroscope can be charged positively by induction in the usual way.

18. Ionisation near the point of the screwdriver will lead to the collection of ions by the screwdriver, positive if the sphere is positive and negative if the sphere is negative. There is eventually a big enough p.d. across the neon bulb to cause it to light.

19. Sharp points will lead to strong fields in their vicinity, ionisation of the air there, collection of ions and consequent drop in voltage on the equipment.

20. Ionisation of the air near the lower point (attached to the 10 kV supply and assumed positive) leads to positive ions moving on to the belt. When positive charge is opposite the point which is attached to the inside of the sphere, a negative charge is induced on the point and a positive charge on the outside of the sphere. Ionisation of the air near the point leads to positive ions being collected by the point and negative ions being collected by the belt. Thus the charge on the belt is cancelled out, positive charge being effectively transferred to the point. All the charge collected flows to the outside of the sphere as the net charge inside a hollow conductor is always zero.

21. The safest place would be inside the dome, where there would be no electric field.

Note that there is a danger, though not immediate, from X-radiation which would be created if fast-moving electrons were to be brought to rest suddenly by the dome. This is why the inside of the dome of the original generator was abandoned as the laboratory.

22. Fairly large areas being brought into contact as one slides over the seat or removes the clothing, leads to transfer of electrons and therefore charging of the surfaces in contact. Sparks may then pass between the surfaces or between either surface and another body.

23. Give to each tyre the same quantity of air at atmospheric pressure by giving the pump the same number of complete strokes. The increase in pressure in the smaller tyre will be much greater than in the larger.

24. The one taking 400 strokes, i.e. the tractor tyre, would have the greater capacity.

25. $Q = CV = 10^{-4} \times 50 = 5 \times 10^{-3}$ coulombs.

$$\text{Average current} = \frac{Q}{t} = \frac{5 \times 10^{-3}}{2 \times 10^{-3}} = 2.5 \text{ A.}$$

26. $Q = CV = 10^{-10} \times 1,200 = 1.2 \times 10^{-7} \text{ C.}$

27. When the battery is momentarily connected to the electro-scope plate, charge flows so that the electrophorus plate and electro-scope case on the one hand and the electro-scope plate and leaf on the other, have equal and opposite charges. The p.d. will not be enough to produce a deflection of the leaf.

The two plates and the conductors attached to them, with the polythene between them form a capacitor. When the upper plate is lifted, the capacity is decreased and so the p.d. is increased; the leaf rises.

Work has been done in pulling the charged plates further apart (see answer to 15). More energy has been stored in the electric field between the plates. This energy has come from the work done in raising the upper plate.

28. See answer to 10.

29. The total capacitance is less than that of each.

Compare the combined capacitor of 49 (c) with one of the originals. The distance between the plates is greater and therefore the capacitance is smaller. The area of the plates has not changed.

30. The total capacitance is greater than that of each. The area of the plates is greater and so the capacitance is greater. The distance between the plates has not changed.

31. (a) If the sheet is of negligible thickness, the capacitance is unchanged. Two capacitors have been formed, each half the thickness and so twice the capacitance of the original. Being in series their combined capacitance equals that of the original capacitor.

(b) As the thickness of each capacitor is now less than half that of the original, the capacitance of each is more than twice that of the original. The total capacitance is increased.

(c) The capacitance is increased (see p. 28).

32. The leaf deflection will increase. As the vanes are opened, the capacitance decreases and therefore the potential difference increases.

33. Nothing.

34. Yes.

35. The rotary pump is similar to the cell and the rubber membrane is similar to the capacitor. As water is pumped round the circuit, the membrane is stretched, thus storing potential energy. While the

membrane is being stretched water is flowing round the circuit. There comes a stage at which the membrane exerts sufficient pressure to balance that of the pump. There being no pressure difference, flow stops.

This situation is similar to that in which the capacitor is fully charged.

If the valve were to be closed and nothing else altered, there would still be no flow.

If a path were provided for a flow of water through another tube connected to either side of the membrane, in effect short-circuiting the pump, the membrane would discharge water through this tube, oscillating for a time depending on its own and the tube's properties.

Compare the effect of the capacitor being allowed to discharge through a conductor connected across it to short-circuit the cell.

36. Connect a centre-zero microammeter (or ballistic galvanometer) in series with the capacitor and the supply (e.g. an E.H.T. unit with voltmeter). As the capacitance is increased and the supply voltage adjusted to remain constant, the ammeter will indicate flow of charge to or from the plates. Two meters, one on each side of the capacitor, would be even better (see 2.21).

37. Charge will flow in the opposite direction.

3 Electrons in Motion $\rightleftharpoons$ Heat (pp. 34-52)

Introduction

Demonstrations 3.1 and 3.2 are modified and extended versions of demonstrations in Chapter 2 of Book Two, illustrating that current is a rate of transfer of charge.

Model 3.3 is worth having made if a good technician is available.

Ohm's Law may be rediscovered (the experiment is in Chapter 10 of Book Two with different components) in Experiment 3.4.

Internal resistance is studied in the next four experiments, models and projects, of which 3.5 and 3.7 are the most important.

Project 3.9 may already have been carried out as an experiment in Chapter 10 of Book Three. Much can be learned from it.

Project 3.10 is worth the time required of the pupil at home.

The main benefit to the pupil from this chapter can come from the chance to become familiar with the basic direct current circuit arithmetic. Time spent, either at school or at home, in attempting as many problems as possible, will not be wasted.

Experimental Work

Demonstration 3.1. When the rate of vibration of the ball is low, the spot kicks in time with the vibrations. When the rate increases (tightening the thread is an effective way of doing this) the current increases and great care has to be taken lest the galvo be damaged. If the slow transfer of charge has been observed on a high-sensitivity setting, the fast rate may be too much for the galvo. Preliminary tests should be carried out and the maximum-sensitivity range capable of coping with a rapid rate of charge transfer found.

Demonstration 3.2. When the supply is switched on, there is a reading on the meter as the plates are charged. Unless there is leakage, the spot should return to its original position.

The insertion of the flame leads to a reading on the meter. The flame has ionised the air, negative and positive ions flowing in opposite directions to the plates constituting a current. The bigger the E.H.T. voltage, the greater the rate of transfer of charge, i.e. the greater the current.

Model 3.3. First find out how high up a tube the table tennis balls can be blown by the vacuum cleaner available. Then decide upon the dimensions of the model!

Experiment 3.4. V/I readings are very nearly constant, i.e. V is directly proportional to I .

The secret of getting good results is the use of a high resistance. Then, as extra cells are added, their internal resistance is negligible. Introduction of extra cells does not effectively change the resistance of the circuit.

Also the high resistance has ensured that the current used is small and so the heating effect is negligible. Temperature has been kept constant. This is important otherwise the resistance of the circuit will change.

A resistor of resistance approximately 600Ω (e.g. 570Ω or 630Ω as available commercially) is satisfactory.

Experiment 3.5. (i) As each bulb is added, the brightness of every bulb becomes less.

(a) The p.d. across each bulb has been reduced.

(b) The current taken from the cells has increased.

(ii) Now there is no apparent change in brightness.

(iii) The situation found in (i) has returned. Each bulb becomes dimmer as bulbs are added. The circuit is like that of (i) because a dry cell has an internal resistance which is not negligible compared with that of the bulbs and it acts like a resistance in series with the cell.

The accumulator has an internal resistance which is negligible compared with that of the bulbs. As the bulbs are disconnected the current taken from the accumulator becomes less, but there is very little change in the p.d. inside it. The p.d. outside it, recorded by the voltmeter, is unlikely to show any change.

There will, however, be considerable change in the p.d. across the 1 ohm resistor. As the current becomes less, this p.d. becomes less and so the p.d. across the remaining bulbs becomes greater.

1.5 V 0.3 A bulbs are also satisfactory. The experiment can be carried out quickly using circuit boards.

Model 3.6. Water is a suitable liquid for the manometer. The model is very effective (N.95).

Experiment 3.7. No comment is necessary.

Experiment 3.8. No comment is necessary.

Project 3.9. See Teachers' Guide to Book Three, experiments 10.7 and 10.8.

Project 3.10. No comment is necessary.

ANSWERS TO QUESTIONS

1. Like charges repel; unlike charges attract.
Like currents attract; unlike currents repel.

2. $I = \frac{Q}{t} = \frac{300}{60} = 5 \text{ A.}$

3. $Q = It = 150 \times 10^{-3} \times 3 \times 60 = 27 \text{ C.}$

4. (a) $Q = CV = 10 \times 10^{-6} \times 40 = 4 \times 10^{-4} \text{ C.}$

(b) $I = \frac{Q}{t} = \frac{4 \times 10^{-4}}{0.2} = 2 \times 10^{-3} \text{ A or } 2 \text{ mA.}$

5. (a) $Q = It = 10 \times 10^{-3} \times 1 = 10^{-2} \text{ C.}$

(b) $Q = \frac{1}{50} \text{ of } 10^{-2} = 2 \times 10^{-4} \text{ C.}$

- (c) The capacitor takes 0.01 second to charge and the same time to discharge. In the first 0.01 s no charge is flowing through the milliammeter. In the second 0.01 s all the charge is flowing through it. Thus the charge flowing to the capacitor and that flowing from it both equal the charge through the meter in 0.02 s, i.e. $2 \times 10^{-4} \text{ C.}$

(d) 10 V.

(e) $C = \frac{Q}{V} = \frac{2 \times 10^{-4}}{10} = 2 \times 10^{-5} \text{ F or } 20 \mu\text{F.}$

6. The rheostat would be used to adjust the voltmeter reading to a suitable value, say about 12 V. The time taken (in seconds) for the temperature of the water to rise by about 10°C would be found, remembering to stir the water well before noting the final temperature.

From $\Delta H = sm\Delta T$, m being expressed in kg and s in J/kg $^\circ\text{C}$, the heat gained (in joules) by the water would be calculated. This heat energy would be taken to equal the amount of electric energy used, assuming that all the electric energy had been converted into heat in the water.

By definition, one volt equals one joule/coulomb. So, if the number of joules of energy used is divided by the number of coulombs, the result is the number of volts applied. The number of coulombs is the product of the current in amperes and the time in seconds.

The number of volts found by calculation will equal the reading on the voltmeter if the voltmeter calibration is correct.

7. 240 V.

(a) Yes.

(b) No (unless there is any contact resistance).

8. (a) 12 V.

(b) 2 A.

(c) 12 J.

(d) 24 J.

9. Ohm's law states that in a conductor at constant *temperature* the current is *directly* proportional to the potential difference across it.

10. (a) $V = IR$.

(b) $I = \frac{V}{R}$.

11. $R = \frac{V}{I} = \frac{12}{3} = 4$ ohms.

12. $V = IR = 10 \times 2.5 = 25$ V.

13. $I = \frac{V}{R} = \frac{240}{60} = 4$ A.

14. Current through the 3 ohm resistor $= \frac{6}{3} = 2$ A.

As the R ohm and 3 ohm resistors are in series, and as the current through the voltmeter is negligible, the current through the R ohm resistor is 2 A.

The value of $R = \frac{10}{2} = 5$ ohms

The total voltage $= 6 + 10 = 16$ V.

The single resistor would have value $= \frac{16}{2} = 8$ ohms.

This is the sum of the values of the two resistors.

15. The current is the same in each resistor. Let it be I amps.

Therefore the current through R_1 , $\frac{V_1}{R_1} = I$,

and the current through R_2 , $\frac{V_2}{R_2} = I$.

The total voltage $V = V_1 + V_2$.

A single resistor, resistance R_s ohms, allowing the same current to flow, would have

$$R_s = \frac{V}{I} = \frac{V_1 + V_2}{I} = \frac{V_1}{I} + \frac{V_2}{I} = R_1 + R_2.$$

16. $I = I_1 + I_2$.

$$I_1 = \frac{12}{3} = 4 \text{ A.} \quad I_2 = \frac{12}{6} = 2 \text{ A.}$$

Therefore $I = 4 + 2 = 6$ A.

If applied voltage were V volts,

$$I_1 = \frac{V}{3} \quad \text{and} \quad I_2 = \frac{V}{6}.$$

Then $I = \frac{V}{3} + \frac{V}{6} = \frac{V}{2}$.

Equating, $\frac{V}{R_p} = \frac{V}{2}$.

Therefore $R_p = 2$ ohms.

$$17. I_1 = \frac{V}{R_1}, \quad I_2 = \frac{V}{R_2}.$$

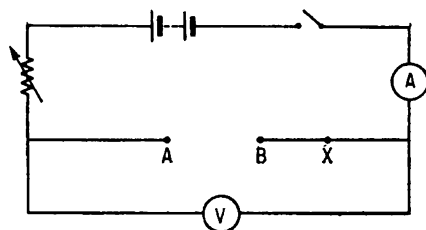
$$I = I_1 + I_2 = \frac{V}{R_1} + \frac{V}{R_2}.$$

$$\text{Also } I = \frac{V}{R_p}. \quad \text{Therefore } \frac{V}{R_p} = \frac{V}{R_1} + \frac{V}{R_2}.$$

$$\text{Therefore } \frac{1}{R_p} = \frac{1}{R_1} + \frac{1}{R_2}.$$

18. In series, the combined resistance is 1,200 ohms; in parallel, it is 300 ohms.

The circuit shown would be used, the resistors being put in the gap AB.



For above-average pupils, the following discussion would be beneficial.

The normal position of the ammeter would only be used if the resistance of the voltmeter were very much greater than that of the combination of resistors. Otherwise so much current would be taken by the voltmeter that the ammeter reading would be much more than the current through the resistors. If the meters recommended in the Preface were used, i.e. the 10 mA f.s.d. ammeter, resistance about 10 ohms, and the 10 V f.s.d. voltmeter, resistance about 1,000 ohms, the ammeter would be moved to position X, where it would read the current through the resistors only. The voltmeter would then give the p.d. across the resistors plus the ammeter, but as the resistance of the latter is very much less than that of the resistors, the error in the voltmeter reading will be negligible.

A 9 V battery could be used.

The variable resistor would have to have a fairly high value, say 5,000 ohms, in order to provide a reasonable range of readings.

In each experiment, V/I would be calculated for a number of settings of the variable resistor and a mean value taken.

$$19. (a) R = R_1 + R_2 + R_3.$$

$$(b) \frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}.$$

In a given case, the right-hand side of this equation would be worked out and the reciprocal taken to find R .

20. (i) (a) $R = 2 + 4 = 6$ ohms.

(b) $R = 15 + 45 = 60$ ohms.

(c) $R = 3 + 4 + 6 = 13$ ohms.

(ii) (a) $\frac{1}{R} = \frac{1}{2} + \frac{1}{4} = \frac{3}{4}$ $R = \frac{4}{3} = 1\frac{1}{3}$ ohms.

(b) $\frac{1}{R} = \frac{1}{15} + \frac{1}{45} = \frac{4}{45}$ $R = \frac{45}{4} = 11.25$ ohms.

(c) $\frac{1}{R} = \frac{1}{3} + \frac{1}{4} + \frac{1}{6} = \frac{3}{4}$ $R = \frac{4}{3} = 1\frac{1}{3}$ ohms.

21. Between B and C, total resistance is given by

$$\frac{1}{R} = \frac{1}{30} + \frac{1}{60} = \frac{1}{20} \quad R = 20 \text{ ohms}$$

Between A and C, total resistance $= 20 + 10$
 $= 30$ ohms.

22. The effective resistance of 40 ohms and 120 ohms in parallel is given by

$$\frac{1}{r} = \frac{1}{40} + \frac{1}{120} = \frac{1}{30} \quad r = 30 \text{ ohms.}$$

Therefore $R = 10 + 30 + 20 = 60$ ohms.

(a) current through 10 ohm resistor $= \frac{6}{60} = 0.1$ A.

(b) current through 120 ohm resistor $= \frac{40}{160} \times 0.1$
 $= 0.025$ A.

Either

The two resistors in parallel have an effective resistance of 30 ohms. If they are replaced by a 30 ohm resistor 0.1 A would flow through it.

The p.d. across the 30 ohm resistor would be $0.1 \times 30 = 3$ V.

Therefore the p.d. across the 40 ohm (and the 120 ohm) resistor $= 3$ V.

Or

The current through the 40 ohm resistor $= 0.075$ A

the p.d. across the 40 ohm resistor $= 40 \times 0.075$
 $= 3$ V.

(ii) Current through the 20 ohm resistor $= 0.1$ A

the p.d. across the 20 ohm resistor $= 20 \times 0.1$
 $= 2$ V.

23. (a) The resistance of each wire $= 1$ ohm.

When the wires are in series their combined resistance equals 2 ohms. As the resistance is doubled, the current is halved. $I = 0.5$ A.

(b) When the wires are connected in parallel, their combined resistance equals $\frac{1}{2}$ ohm. As the resistance is halved, the current is doubled. $I = 2$ A.

24. (a) Resistance is directly proportional to the length.

(b) Resistance is inversely proportional to the cross-sectional area.

(i) When two resistors are connected in series, their combined length is greater than that of either alone, and so their combined resistance is greater than that of either alone.

(ii) When two resistors are connected in parallel, their combined area of cross-section is greater than that of either alone, and so their combined resistance is less than that of either alone.

25. A good voltmeter should have a high resistance, so that, when it is connected in parallel with the part of a circuit across which the p.d. is required, it takes a very small current from the circuit. In this way the p.d. across the part of the circuit is not changed appreciably by the insertion of the voltmeter.

An ammeter is connected in series with that part of a circuit being investigated, and, so that its effect on the current flowing should be as little as possible, should have a low resistance.

26. The combined resistance of the two 6 ohm resistors in parallel is 3 ohms. The total resistance of the circuit is therefore 6 ohms, and the current taken from the battery, from $I = V/R$, is 1 A. Thus the reading on A_1 is 1 A. Half the current goes through each 6 ohm resistor and so the reading on A_2 is 0.5 A.

The p.d. across the 3 ohm resistor, from $V = IR$, is 3 volts. This is the reading on V.

27. Resultant e.m.f. in circuit = $6 - 2 = 4$ V.

Effective resistance of the resistors in parallel is given by

$$\frac{1}{r} = \frac{1}{5} + \frac{1}{20} = \frac{1}{4}. \quad \text{Therefore } r = 4 \text{ ohms.}$$

Total resistance of the circuit = $1 + 2 + 4 + 1 = 8$ ohms.

Therefore current, i.e. meter reading = $4/8 = 0.5$ A.

The current through the 20 ohm resistor = $\frac{5}{25} \times 0.5 = 0.1$ A.

The p.d. across the 2 ohm resistor = $0.5 \times 2 = 1$ V.

The direction of the electron flow is clockwise.

28. Consider the resistors in parallel. The effective resistance, x , of the three resistors is given by

$$\frac{1}{x} = \frac{1}{4} + \frac{1}{8} + \frac{1}{8} = \frac{1}{2}. \quad \text{Therefore } x = 2 \text{ ohms.}$$

The effective resistance, y , of the two resistors is given by

$$\frac{1}{y} = \frac{1}{3} + \frac{1}{6} = \frac{1}{2}. \quad \text{Therefore } y = 2 \text{ ohms.}$$

Therefore the total resistance = $6 + 2 + 10 + 2 = 20$ ohms

and the resultant e.m.f. = $12 + 8 = 20$ V.

Therefore the current from the batteries = $\frac{20}{20} = 1$ A.

Reading on A_1 and A_3 = 1 A.

Reading on $A_4 = \frac{6}{9} \times 1$ A = 0.67 A.

Reading on $A_5 = \frac{3}{9} \times 1$ A = 0.33 A.

The p.d. across the resistors in parallel, considering their effective resistance and the current which would flow through it, $= 1 \times 2 = 2$ V.

Therefore the current through the 8 ohm resistor $= 2/8 = 0.25$ A. This is the reading on A_2 .

The reading on $V_1 = 1 \times 6 = 6$ V.

The reading on $V_2 = 12 - 1 \times 10 = 2$ V.

29. The cell is everything inside the red rectangle.

t.p.d. $= 1.5 - 0.2 = 1.3$ V.

As R is increased, the current will decrease. The t.p.d. will then increase.

30. When he switches on the starter motor, a large current is taken from the battery. This leads to a reduction in the t.p.d. of the battery and so a smaller p.d. across each headlight.

31. Their internal resistance is relatively high. Also, any attempt to take a high current from them would lead to rapid polarisation and consequent increase in internal resistance.

32. Total e.m.f. $= 3$ V.

(a) Total resistance $= 12$ ohms.

Therefore current $= \frac{3}{12} = 0.25$ A.

Therefore t.p.d. $= 0.25 \times 10 = 2.5$ V.

(b) Total resistance $= 1,002$ ohms.

Therefore current $= \frac{3}{1,002} = 3 \times 10^{-3}$ A (approx.).

Therefore t.p.d. $= 3 \times 10^{-3} \times 10^3 = 3$ V.

The 1,000 ohm voltmeter is the better one.

33. (a) Total resistance $= 5$ ohms.

Therefore current $= 1.5/5 = 0.3$ A.

(b) Total resistance $= 7$ ohms.

Total e.m.f. $= 3$ V.

Therefore current $= 3/7 = 0.43$ A.

(c) The effective resistance of the two cells in parallel is 1 ohm.

Therefore the total resistance is 4 ohms.

The total e.m.f. $= 1.5$ V.

Therefore the current $= \frac{1.5}{4} = 0.38$ A.

34. The total resistance of the circuit must be $2/2 = 1$ ohm.

Therefore the value of the external resistance needed $= 0.9$ ohms.

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'lost volts' = $2 \times 0.1 = 0.2$ V.

35. If there is no reading on the voltmeter, there can be no current in the circuit. The resultant e.m.f. must be zero. This could be produced by having another 1.5 V cell in series with, but in opposition to, the original cell. Alternatively, more than two cells could be in the circuit, of such an e.m.f., and connected in such a way, that the resultant e.m.f. was zero.

36. The effective e.m.f. is about 8 volts.

The total resistance must = $8/2 = 4$ ohms.

Therefore the additional resistance required = $4 - 0.6$
= 3.4 ohms.

This should be reduced as the e.m.f. of the battery rises.

37. If the cells are connected in *series*,

total e.m.f. = 7.5 V,

total resistance = 5.2 ohms,

and therefore current = $\frac{7.5}{5.2} = 1.4$ A.

If the cells are connected in *parallel*,

total e.m.f. = 1.5 V,

total resistance = 0.2 (resistance of the five 1 ohm internal resistances in parallel) + 0.2
= 0.4 ohms,

and therefore current = $\frac{1.5}{0.4} = 3.75$ A.

The parallel arrangement gives the greater current.

One large cell would normally be used because it would have a much smaller internal resistance than a number of small cells. One large cell is equivalent to a number of smaller cells in parallel.

38. Dry cell $r = \frac{1.5}{3} = 0.5$ ohms.

Accumulator $r = \frac{2}{200} = 0.01$ ohms.

If an accumulator is short-circuited, the extremely high current flowing will lead to the generation of much heat in the accumulator plates as well as in the external circuit. The plates may be buckled badly or even caused to disintegrate.

39. The maximum e.m.f. would be obtained by connecting the batteries in series, with the positive of one to the negative of the other.

The voltmeter would read 6 V. A very small current would flow through it and the batteries. Removal of the voltmeter (and its high resistance) would lead to a much larger current flowing. Electron flow would be from the negative terminal of the 9 V battery and into the negative terminal of the 3 V battery.

40. In each case *all* the cells are connected in series with each other and the resistor. In this way the total resistance is constant. Then to produce 1 unit of current, 3 cells should face one way and 2 the other, giving a resultant e.m.f. of $3E - 2E = E$. Similarly, 4 one way and 1 the other give $3E$ and so 3 units of current, and all facing the same way give $5E$ and 5 units of current.

41. Total resistance $= 8/1 = 8$ ohms.

Resistance x of the three resistors in parallel is given by

$$\frac{1}{x} = \frac{1}{4} + \frac{1}{5} + \frac{1}{20} = \frac{10}{20} = \frac{1}{2}. \quad \text{Therefore } x = 2 \text{ ohms.}$$

Therefore the internal resistance of the battery
 $= 8 - (2 + 4) = 2$ ohms.

42. Rate of production of heat

= rate of consumption of electrical energy (power)

$$= \frac{VIt}{t} = VI$$

$$= IR \times I = I^2 R$$

$$\text{or } = V \times \frac{V}{R} = \frac{V^2}{R}$$

43. Current $= \frac{60}{240} = 0.25$ A.

44. $P = \frac{V^2}{R}$ Therefore $R = \frac{V^2}{P} = \frac{36}{12} = 3$ ohms.

45. $V = \frac{P}{I} = \frac{2,000}{20} = 100$ V.

46. $R = \frac{V^2}{P}$.

$$60 \text{ watt lamp: } R = \frac{240 \times 240}{60} = 960 \text{ ohms.}$$

$$150 \text{ watt lamp: } R = \frac{240 \times 240}{150} = 384 \text{ ohms.}$$

47. $P = VI = 6 \times 0.5 = 3$ W $= 3$ J/s.

i.e. 3 joules are transformed in each second.

48. $I = \frac{P}{V} = \frac{1,000}{250} = 4$ A.

$$R = \frac{V}{I} = \frac{250}{4} = 62.5 \text{ ohms.}$$

If the power is reduced to 500 W,

$$I^2 = \frac{P}{R} = \frac{500}{62.5} = 8 \quad \text{Therefore } I = \sqrt{8} = 2\sqrt{2} \text{ A.}$$

$$\text{Then total resistance} = \frac{250}{2\sqrt{2}} = \frac{250\sqrt{2}}{4} = 62.5\sqrt{2} \text{ ohms.}$$

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$$\begin{aligned}\text{The additional resistance needed} &= 62.5\sqrt{2} - 62.5 \\ &= 62.5 \times 0.414 \\ &= 25.9 \text{ ohms.}\end{aligned}$$

$$\begin{aligned}\text{Power taken from the supply} &= VI = 250 \times 2\sqrt{2} \\ &= 500\sqrt{2} = 707 \text{ W.}\end{aligned}$$

$$49. (a) P = \frac{V^2}{R} = \frac{240 \times 240}{60} = 960 \text{ W.}$$

$$(b) P = VI = 12 \times 5 = 60 \text{ W.}$$

$$(c) P = \frac{VQ}{t} = \frac{20 \times 10^3 \times 0.02}{10^{-3}} = 0.4 \times 10^6 \text{ W or } 400 \text{ kW.}$$

$$(d) P = VI = 20 \times 5 = 100 \text{ W.}$$

$$50. P = VI = 12 \times 4 = 48 \text{ W.}$$

Therefore 48 joules of energy are supplied in one second.

$$\begin{aligned}\text{Total energy required} &= sm\Delta T \\ &= 4,200 \times 0.2 \times 10 = 8,400 \text{ J.}\end{aligned}$$

$$\text{Therefore the time taken} = \frac{8,400}{48} = 175 \text{ s} = 2 \text{ min } 55 \text{ s.}$$

$$\begin{aligned}51. \text{ Total energy supplied} &= sm\Delta T \\ &= 4,200 \times 1 \times 60 \\ &= 252 \times 10^3 \text{ J.}\end{aligned}$$

$$\text{Power of heater} = \frac{252 \times 10^3}{2 \times 60} = 2,100 \text{ W.}$$

$$\text{But } P = \frac{V^2}{R} \text{ and so } R = \frac{V^2}{P} = \frac{240 \times 240}{2,100} = 27.3 \text{ ohms.}$$

$$52. (a) R = \frac{V^2}{P} = \frac{250 \times 250}{500} = 125 \text{ ohms.}$$

$$(b) P = VI, \text{ and so } I = \frac{P}{V} = \frac{500}{250} = 2 \text{ A.}$$

$$\text{or } I = \frac{V}{R} = \frac{250}{125} = 2 \text{ A.}$$

$$(c) \text{ In 1 s, heat produced} = 500 \text{ J.}$$

$$\begin{aligned}\text{Therefore in 10 min, heat produced} &= 500 \times 600 \\ &= 3 \times 10^5 \text{ J.}\end{aligned}$$

$$\begin{aligned}53. \text{ Energy which can be stored} \\ &= \text{energy which can be delivered} = VIt \\ &= 2 \times 100 \times 3,600 = 7.2 \times 10^5 \text{ J.}\end{aligned}$$

$$\begin{aligned}54. \text{ In 1 s, energy used by motor} &= 1,000 \text{ J.} \\ \text{Therefore in 10 min, energy used} &= 1,000 \times 600 \text{ J.} \\ 30\% \text{ of this energy is wasted and is changed into heat.}\end{aligned}$$

$$\begin{aligned}\text{Therefore the heat produced in 10 min} &= \frac{30}{100} \times 1,000 \times 600 \\ &= 1.8 \times 10^5 \text{ J.}\end{aligned}$$

55. Current required by bulb is given by

$$I = \frac{P}{V} = \frac{36}{12} = 3 \text{ A.}$$

p.d. across bulb must be 12 V, and so p.d. across series resistance must be 8 V.

$$\text{Therefore } R = \frac{V}{I} = \frac{8}{3} = 2.7 \text{ ohms.}$$

56. Original current in each light = $\frac{P}{V} = \frac{240}{240} = 1 \text{ A.}$

$$\text{Resistance of each light} = \frac{V}{I} = \frac{240}{1} = 240 \text{ ohms.}$$

The lights will be connected in parallel and so the total resistance = $1/30$ of $240 = 8 \text{ ohms.}$

To reduce the current to $1/3$ of its original value, an additional 16 ohm resistance is needed.

The original current from the supply = 30 A.

When it is reduced to 10 A, all this current must pass through the 16 ohm resistor. The power dissipated in the latter = $I^2 R = 10 \times 10 \times 16 = 1,600 \text{ W}$ or 1.6 kW.

$$57. P = I^2 R \quad \text{Therefore } I^2 = \frac{P}{R} = \frac{2}{100}$$

$$\text{Therefore } I = \frac{\sqrt{2}}{10} = 0.14 \text{ A.}$$

$$\text{Then p.d. across it} = IR = \frac{\sqrt{2}}{10} \times 100 = 14 \text{ V.}$$

$$58. P = I^2 R = 50 \times 10^{-3} \times 50 \times 10^{-3} \times 10^3 \\ = 2.5 \text{ W.}$$

A 5 W resistor would be chosen.

$$\text{p.d. across resistor} = IR = 50 \times 10^{-3} \times 10^3 = 50 \text{ V.}$$

59. When charged to 1,000 V, the capacitor stores a definite amount of energy, which is converted into heat when the capacitor is discharged through a resistor. The amount of heat produced is constant and so does not depend on the value of the resistor.

The answer is (a).

$$60. E = QV = 3 \times 50 = 150 \text{ J.}$$

$$61. E = QV = 1.6 \times 10^{-19} \times 2 \times 10^6 = 3.2 \times 10^{-13} \text{ J.}$$

$$62. E = QV = 700 \times 12 = 8,400 \text{ J.}$$

If the car were to be raised h metres, the P.E. gained would be $700 \times 10 \times h \text{ J}$ (taking $g = 10 \text{ m/s}^2$).

$$\text{Therefore } h = \frac{8,400}{700 \times 12} = 1.2 \text{ m.}$$

$$Q = It$$

$$\text{Average current } I = \frac{Q}{t} = \frac{700}{3.5} = 200 \text{ A.}$$

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Average power = $V \times$ average $I = 12 \times 200 = 2,400$ W or 2.4 kW.

63. Average current $I = \frac{Q}{t} = \frac{20}{10^{-2}} = 2,000$ A.

Energy transformed = $QV = 20 \times 10^9 = 2 \times 10^{10}$ J.

Power transformed = $\frac{2 \times 10^{10}}{10^{-2}} = 2 \times 10^{12}$ W.

64. Current through each bulb = $\frac{P}{V} = \frac{24}{12} = 2$ A.

Therefore current taken from battery = 4 A.

Resistance of each bulb = $\frac{V}{I} = \frac{12}{2} = 6$ ohms.

When the bulbs are in series, total resistance = 12 ohms.

Therefore the current = $\frac{V}{R} = \frac{12}{12} = 1$ A.

The current taken from the battery would be less because the internal resistance of the battery would make the total resistance greater than that used in the calculation.

65. (a) $Q = It = 5 \times 60 = 300$ C.

(b) $E = QV = 300 \times 20 = 6,000$ J.

66. $Q = It$ Therefore $t = \frac{Q}{I} = \frac{10}{2} = 5$ s.

$E = VIt$ Therefore $t = \frac{E}{VI} = \frac{600}{30 \times 2} = 10$ s.

67. The lamps would be wired in series.

Total energy transformed = VIt
 $= 240 \times 0.3 \times 20 \times 60$
 $= 8,640$ J.

68. 12 V bulb: $I = \frac{P}{V} = \frac{24}{12} = 2$ A.

240 V bulb: $I = \frac{P}{V} = \frac{24}{240} = 0.1$ A.

The 240 V bulb filament will be longer.

The 12 V bulb filament will be thicker.

Both are rated at 24 W and so will use the same energy per second.

Resistance of 12 V bulb = $\frac{V}{I} = \frac{12}{2} = 6$ ohms.

Resistance of 240 V bulb = $\frac{V}{I} = \frac{240}{0.1} = 2,400$ ohms.

69. Power = I^2R and, assuming that resistance is constant (it will increase as the temperature of the wire is raised), power $\propto I^2$.

If the current is doubled, the power is four times what it was. Therefore the heat produced per second is four times what it was.

70. Resistance of each bulb $= \frac{V^2}{P} = \frac{100 \times 100}{100} = 100$ ohms.

Combined resistance $= 200$ ohms.

Total power dissipated $= \frac{V^2}{R} = \frac{240 \times 240}{200} = 288$ W.

Power dissipated in each bulb $= 144$ W.

71. Current taken by fire $= \frac{P}{V} = \frac{2,000}{250} = 8$ A.

Current taken by toaster $= \frac{P}{V} = \frac{1,000}{250} = 4$ A.

Current taken by cleaner $= \frac{V}{R} = \frac{250}{125} = 2$ A.

Therefore current taken from the supply $= 14$ A.

72. The power consumed by the element $= \frac{V^2}{R}$ and V is constant.

Shortening the wire reduces the resistance and so increases the power. More heat will be produced per second.

73. (a) Rate of production of heat would be doubled ($P = I^2 R$).

(b) Rate of production of heat would be halved ($P = V^2/R$).

(c) Rate of production of heat would be four times
original ($P = I^2 R$).

(d) Rate of production of heat would be doubled ($P = VI$).

(e) Rate of production of heat would be doubled ($P = VI$).

(f) Rate of production of heat would be four times
original ($P = V^2/R$).

74. Output energy $=$ energy used in raising lift
 $= 1,000$ (newtons) $\times 60 = 6 \times 10^4$ J.

Input energy $= VI t = 250 \times 100 \times 40 = 10^6$ J.

Efficiency $= \frac{\text{output energy}}{\text{input energy}} = \frac{6 \times 10^4}{10^6} = 6\%$.

75. 1 kWh $= 1,000$ watts $\times 3,600$ seconds
 $= 36 \times 10^5$ watt seconds $= 36 \times 10^5$ J.

76. Energy used $= 2 \times 10 = 20$ kWh.

Cost $= 20 \times 2 = 40$ pence $= 3/4$.

77. (a) immersion heater: energy used $= 3 \times 5 = 15$ kWh.

cost $= 15 \times 2$ pence $= 2/6$.

lamp: energy used $= 0.1 \times 100 = 10$ kWh.

cost $= 10 \times 2$ pence $= 1/8$.

(b) One match costs $3/50$ pence $= 0.06$ pence.

2 pence is the cost of 1 kWh.

Therefore 0.06 pence is the cost of $\frac{1}{2} \times 0.06$, i.e. 0.03 kWh.

If x is the number of hours the lamp could be run, then
 $0.1x = 0.03$.

Therefore $x = 0.3$ hr $= 18$ min.

$$78. \text{Energy required} = sm\Delta T = 4,200 \times 2 \times 80 \\ = 672,000 \text{ J.}$$

$$\text{Power of supply} = 2 \text{ kW} = 2,000 \text{ J/s.}$$

Therefore the time to bring the kettle to the boil

$$= \frac{672,000}{2,000} = 336 \text{ s} = 5 \text{ min } 36 \text{ s.}$$

$$\text{Total energy used} = 2 \times \frac{336}{3,600} = \frac{56}{300} \text{ kWh.}$$

$$\text{Cost} = \frac{56}{300} \times 2 = \frac{112}{300} = 0.37 \text{ pence.}$$

$$\text{Energy required to boil away the water} = mL \\ = 2 \times 22.6 \times 10^5 \\ = 45.2 \times 10^5 \text{ J.}$$

$$\text{Therefore the time needed} = \frac{45.2 \times 10^5}{2,000} = 2,260 \text{ s} \\ = 37 \text{ min } 40 \text{ s.}$$

$$\text{Total energy used} = 2 \times \frac{2,260}{3,600} \text{ kWh.}$$

$$\text{Cost} = 2 \times \frac{2,260}{3,600} \times 2 = 2.5 \text{ pence.}$$

79. A well filled bath will contain about 300 kg of water.

Assuming that the water is originally at about 15°C and that 45°C is a comfortable final temperature, the energy required to heat the water $= sm\Delta T$

$$= 4,200 \times 300 \times 30$$

$$= 378 \times 10^5 \text{ J}$$

$$= 378 \times 10^5 \text{ Ws}$$

$$= \frac{378 \times 10^5}{36 \times 10^5} \text{ kWh}$$

$$= 10.5 \text{ kWh.}$$

$$\text{Cost} = 10.5 \times 2 = 21 \text{ pence} = 1/9.$$

80. Clearly, a rough estimate is all that is required, but a reasonably accurate solution is given here.

On the bridge itself, there are about 120 lamps. The power has been changed from time to time, but at the time of going to press is 200 W.

Taking the average time during which the lamps are lit each day to be 12 hours,

$$\text{the cost/lamp/day} = 0.2 \times 12 \times 2 \text{ pence}$$

$$\text{the cost/120 lamps/year} = \frac{\pounds 0.2 \times 12 \times 2 \times 120 \times 365}{20 \times 12}$$

$$= \pounds 876.$$

81. Storage heaters: Energy used $= 4 \times 3 \times 12 = 144 \text{ kWh.}$

$$\text{Cost/day} = 144 \times 0.8 = 115.2 \text{ pence} = 9/7.$$

Ordinary heaters: Energy used $= 6 \times 2 \times 6 = 72$ kWh.

Cost/day $= 72 \times 2 = 144$ pence $= 12/-$.

82. The energy supplied by the hot plate does not all get to the water in the kettle. Some will be used to heat parts of the cooker and some will pass directly to the air.

83. Power of bulb $= 2.5 \times 0.3 = 0.75$ W $= 0.75 \times 10^{-3}$ kW.

Energy used in 3 hr $= 0.75 \times 10^{-3} \times 3$ kWh

$= 2.25 \times 10^{-3}$ kWh.

2.25×10^{-3} kWh cost 1/-.

Therefore 1 kWh costs $\frac{1}{2.25 \times 10^{-3}} = \frac{1,000}{2.25} = 444.4/-$
 $= \pounds 22.4.5$.

84. Both lamps convert electric energy at the same rate, but much of this energy is converted to heat in the tungsten lamp. The fluorescent lamp is thus more efficient and gives more light than the tungsten lamp.

They cost the same to run.

85. Electric energy.

86. Appliance	Power	Current	Fuse
convector	3 kW	12.5 A	13 A
kettle	2 kW	8.3 A	10 A
radiant heater	1.5 kW	6.3 A	10 A
slide projector	1 kW	4.2 A	5 A
electric iron	800 W	3.3 A	5 A
vacuum cleaner	600 W	2.5 A	5 A
hair dryer	500 W	2.1 A	5 A
cine projector	300 W	1.3 A	2 A
TV set	200 W	0.8 A	2 A
electric blanket	150 W	0.6 A	2 A
refrigerator	120 W	0.5 A	2 A
table lamp	75 W	0.3 A	2 A

It is likely that the fuse values available in future will be fewer than those considered here.

87. The cell, bulb and ammeter (f.s.d. of 100 mA or not much more will be suitable) would be connected in series. The voltmeter (f.s.d. 1.5 V suitable) would be connected across the bulb.

Readings of p.d. V, and current, I, would be taken and V/I calculated. This is the resistance of the bulb.

11.7 ohms is the resistance of the bulb at its operating temperature, when a current of 0.3 A is passing through it. In the experiment, the current will have a maximum value of about 0.1 A, the bulb will be at a fairly low temperature and its resistance will consequently be lower.

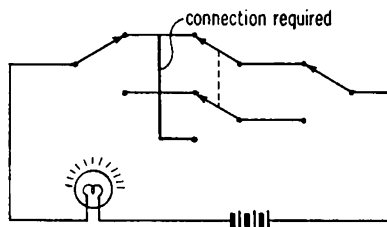
88. The resistance is not ohmic because the graph does not pass through the origin.

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As soon as a p.d. is applied, oxygen collects on the anode, causing polarisation. The back e.m.f. set up by the platinum and oxygen has to be overcome before the current will flow.

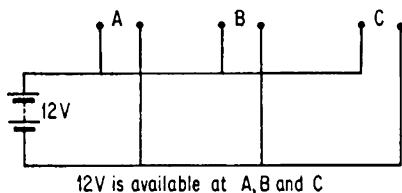
Had the electrodes been of copper, there would have been no polarisation and so the graph would have passed through the origin.

89.



90. You are less likely to get a shock because the current which may flow because of the fault is more likely to flow to earth via the wire provided than through your body, the path via the wire being the path of least resistance. If there is no earth wire, the case of the instrument, for example, may be live, and anyone touching it would provide a path for the flow of current to earth and so would receive a shock.

91. Each pair of terminals is connected directly to the poles of the battery so that any appliances used are in parallel with each other.



Total current through the battery = 10 A.

Therefore p.d. inside the battery (lost volts) = $10 \times 0.2 = 2$ V.

Therefore t.p.d. of battery, i.e. p.d. at the third pair of terminals = $12 - 2 = 10$ V.

92. If a number of adaptors are used as shown, the number of appliances in use at the same time may be so large that the total current is more than the house wiring (or the adaptor plugged into the wall socket) is designed to take.

It might not be advisable to point out that there is no danger in using a large number of appliances on the same 13 amp socket provided the total current does not exceed 13 A!

93. Let the resistance of each bulb be r ohms. Let the internal

resistance of the battery be negligible and let its e.m.f. be E volts. When the switch is open, the current through each bulb $= E/2r$ A. When the switch is closed, B and C are in parallel and their combined resistance $= r/2$ ohms. The total resistance of the circuit is then $= 3r/2$ ohms.

The current taken from the battery now $= 2E/3r$ amperes. Therefore the current through bulb A is $2E/3r$ amperes, which is more than before and so bulb A becomes brighter.

The current through bulbs B and C $= E/3r$. Therefore B and C are equally bright, but less bright than B was before the switch was closed.

94. The resistance of the 6 V 0.3 A bulb $= \frac{6}{0.3} = 20$ ohms.

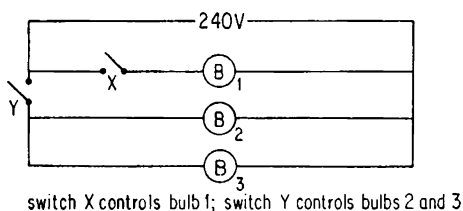
The resistance of the 6 V 0.04 A bulb $= \frac{6}{0.04} = 150$ ohms.

The total resistance $= 170$ ohms.

Therefore the current through each bulb $= \frac{12}{170} = 0.07$ A.

As this is much less than that required for the 6 V 0.3 A bulb and much more than that required for the 6 V 0.04 A bulb, the former will light dimly, if at all, and the latter will shine brightly, perhaps burning out.

95.



Switch 1 controls bulb 1.

Switch 2 controls bulbs 2 and 3.

96. The intention is that the pupil should draw five separate circuit diagrams, showing, for example:

1. one element, 2. two elements in series,
3. three elements in series, 4. two elements in parallel,
5. three elements in parallel.

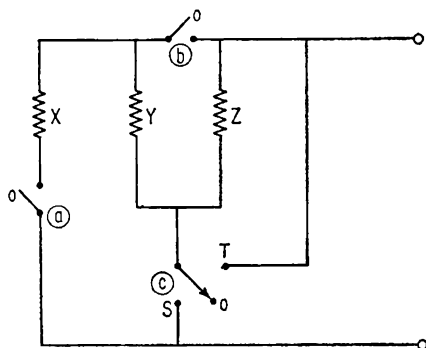
One way of combining them in one circuit is shown in Figure 8. The elements are X, Y and Z.

To get successively greater rates of heating, connect

(i) three elements in series (close (a)),

(ii) two elements in series (close (a) and put (c) to T),

- (iii) one element (close (a) and (b)),
 (iv) two elements in parallel (close (b) and put (c) to S),
 (v) three elements in parallel (close (a) and (b) and put (c) to S).



$$\begin{aligned}
 97. \text{ Energy released} &= 4 \times 10^{15} \text{ J} \\
 &= 4 \times 10^{15} \text{ Ws} \\
 &= \frac{4 \times 10^{15} \times 10^{-3}}{36 \times 10^2} \text{ kWh} = \frac{10^{10}}{9} \\
 &= 1.1 \times 10^9 \text{ kWh.}
 \end{aligned}$$

$$\text{Cost at two pence per kWh} = \frac{10^{10} \times 2}{9} = \text{£}9.3 \times 10^6.$$

98. This is done for safety. An ordinary wall switch, possibly with condensed steam on its surface, might well conduct electricity to the hand, particularly if the latter is wet.

99. The component is ohmic. It is probably a resistor.

100. The lamp could be dimmed but the arrangement is not satisfactory.

The resistance of a quartz-iodine headlamp bulb is about 1.5 ohms. If the resistance of the variable resistor is adjusted to be much more than that, then the effective resistance will be that of the bulb. Then nearly all the current will pass through the bulb, making it light brightly.

If the variable resistor is adjusted to have a value about the same as that of the lamp, the effective resistance, ignoring the resistance of the battery, will be half that of the lamp. Then twice as much current will be taken from the battery. The lamp will take half of it and will be just as bright as before. The battery may be damaged by a sustained current of about 17 A. The variable resistor will have to dissipate about 100 W.

If the variable resistor were reduced further, the lamp would receive less current and would become dimmer, but much more current would be taken from the battery and much more power would have to be dissipated by the variable resistor.

The variable resistor should be in series with the lamp.

101. The pupil has obviously confused the functions of ammeter and voltmeter. The voltmeter will have a high resistance and so the current taken from the battery will be very small. The ammeter will indicate a very small current. The voltmeter will read the p.d. between the negative terminal of the battery and the 'top' resistor. As the ammeter resistance will be low, the combined resistance of it and the resistor in parallel with it will be low (much less than the voltmeter resistance). Thus the resistance of the top resistor is that which will have most effect on the voltmeter reading. If the resistance is small compared with that of the voltmeter, the reading on the latter will be not much less than the terminal p.d. of the battery; as the resistance increases, the voltmeter reading will decrease.

102. An electric fire uses electric energy at a high rate, i.e. its power is high.

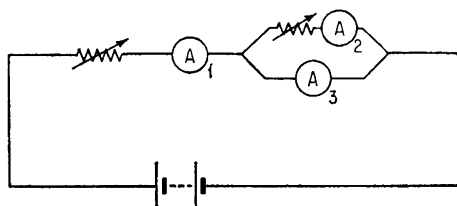
$$\begin{aligned}
 \text{103. In 5 hours, the energy produced} &= 50 \times 5 \times 3,600 \text{ J} \\
 &= 9 \times 10^5 \text{ J} = 9 \times 10^5 \text{ Ws} \\
 &= \frac{9 \times 10^5}{10^3 \times 3,600} \text{ kWh} = 0.25 \text{ kWh}
 \end{aligned}$$

$$\text{Cost} = 2 \times 0.25 = 0.5 \text{ pence.}$$

You get your energy from the food you eat and from respiration.

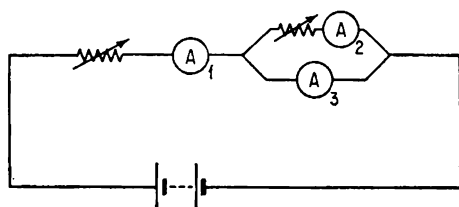
104. Connect the ammeters, the battery and one rheostat in series. Adjust the rheostat so the current is 1 A as indicated on the marked meter. Mark the 1 A value on the other ammeters.

Now assemble the circuit shown.



Adjust the rheostat so that meter 1 reads 1 A. Now 0.5 A passes through the other meters; mark them accordingly. Now adjust the current so that the meters in parallel read 1 A. Meter 1 has 2 A passing through it; mark it. By reassembling the meters in series, each may be marked 0.5 and 2 A. By using the circuit above again, the 0.25 A markings may be obtained.

Next connect this circuit:



By suitably adjusting the rheostats, e.g. so that meter 2 reads 0.5 A and meter 3 0.25 A, giving 0.75 A on meter 1, and by reusing the previous circuits, the remaining markings may be obtained.

105. Electricity is produced by thermocouples and in power stations, which use as their energy source either coal, water, or nuclear fuel such as plutonium. In each case, the fuel has been formed or has been raised to its position, by the action of heat from the sun.

4 Electrons in Motion $\rightleftharpoons$ Chemical Change (pp. 53–57)

Introduction

The purpose of this chapter is to recall the chemical effect of an electric current first observed in Book Two, page 30 and to determine the factors governing the mass of substance liberated in electrolysis, i.e. Faraday's First Law only. Only physical uses of electrolysis need be considered, e.g. electroplating.

One might set the scene for this work by looking at the conditions under which the electrolysis of potassium iodide takes place as a demonstration and to deal with Practical Puzzle 1 at the same time. Experiment 4.1 (i), (ii) and (iii), or 4.1 (c) are the only pupil experiments and must be done. A discussion of electroplating and either project 1 or 2 complete the work, the problems being set as homework.

The whole of the work should not occupy more than four periods.

Experimental Work

Experiment 4.1. All pupils must do this.

(a) This apparatus is adequate, the cathode can be of the form shown in Fig. 100 which saves drilling.

(i) Gas is hydrogen.

(ii) Volume and hence mass vary directly with time.

(iii) The time taken to collect two volumes varies inversely as the current.

(b) A demonstration only to be done if time is at a premium.

(c) The mass liberated is directly proportional to current and to time.

Projects 4.2 and 4.3. No comment needed.

ANSWERS TO QUESTIONS

1. Apparently nothing since the current is so minute that the bulb will not show it. Ions provided by the dissolved common salt (i.e. Na^+ and Cl^-) become charge carriers and the bulb lights. Hydrogen is released from the cathode and chlorine from the anode.

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2. Mass of hydrogen = $(1 \times 5 \times 60) (6.24 \times 10^{18}) (1.67 \times 10^{-27})$
 $= 3.1 \times 10^{-6} \text{ kg.}$

3. $I = \frac{10^{-3}}{3.3 \times 10^{-7} \times 7,200} = 0.42 \text{ ampere.}$

4. $m = zIt \quad \therefore I = \frac{m}{zt} = \frac{0.66 \times 10^{-3}}{3.3 \times 10^{-7} \times 30 \times 60} = 1.1 \text{ A.}$

Ammeter is reading low; should read 1.1 ampere.

5. $\frac{m}{It} = z$ Hence $Iam.$

(a) If mass is lost calibration will be low.

(b) If mass is gained calibration will be high.

In (a) a high reading on the meter will be calibrated as a lower one and vice versa in (b). Oxidation means a gain of mass.

6. Mass = $2 \times 2 \times 3,600 \times 3.3 \times 10^{-7} \text{ kg.}$

Volume = $\frac{2 \times 2 \times 3,600 \times 3.3 \times 10^{-7}}{9 \times 10^3} \text{ m}^3.$

Thickness = $\frac{2 \times 2 \times 3,600 \times 3.3 \times 10^{-7}}{9 \times 10^3 \times 72 \times 10^{-4}} \text{ m}$

$= \frac{6.6}{9 \times 10^4} \text{ m}$

$= 0.73 \times 10^{-4} \text{ m}$

$= 0.0073 \text{ cm.}$

7. Time = $\frac{2}{1.118 \times 10^{-3}} = 1,789 \text{ s} = 29 \text{ m } 49 \text{ s.}$

8. Quantity = $2 \times 2 \times 60 \text{ C.}$

Mass of copper = $\frac{240 \times 6.24 \times 10^{18} \times 1.05 \times 10^{-25} \text{ kg}}{1.118 \times 10^{-6}}$
 $= 7.86 \times 10^{-5} \text{ kg.}$

Check:

Mass of copper = $3.3 \times 10^{-7} \times 240 \text{ kg} = 7.92 \times 10^{-5} \text{ kg.}$

5 Electrons in Motion $\rightleftharpoons$ Magnetic Field (pp. 58–77)

Introduction

Electromagnetism is a vital piece of work in which pupils discover fundamental physical concepts which are important not only in pure science but also lead to an understanding of many electrical devices in common use. The bulk of the work can be carried out at pupil level using the Westminster Electromagnetic Kit and low voltage electrical sources. A host of simple direct experiments are given and it is by no means necessary to do them all. The following series of experiments is suggested to cover the work:

1, 2, 4; 6, 7; 11, 12, 13; 14; 17; 20; 23; 30; 32; 35 (a), 36, 37, 38, 39 (a); 43; 40, 41, 42.

Using the stations technique for experiments 35 (a) to 43 (above) the pupils may be led to discover the very important Lenz Law for themselves. Experiment 43 (laminations) is included although it is an optional extra, as the C-cores in the kit are laminated and lamination will be met in a later chapter on transformers.

The only quantitative work is that associated with shunts and multipliers and many of the problems on these and other topics as well as some projects are very suitable as homework.

Some 10–12 periods are required for this work.

Experimental Work

Experiment 5.1. As an alternative to an accumulator, a labpack fitted with an overload cut-out can be used but in either case only switch on for two seconds. The current flows in the same direction in each wire at all times whether using d.c. or a.c. and the wires move towards one another, i.e. the charges are always moving in the same direction in the two wires.

Experiment 5.2. The wires move apart, as the current is flowing in opposite directions in the loops.

Experiment 5.3. No comment is needed.

Experiment 5.4. (i) (a) Coils move closer together.

(b) Coils move further apart.

(Assuming that the coils are wound in the same sense.)

The force is greater between the coils than between single wires. The wire is 26 swg plastic covered.

(ii) The force between the two coils is greatly increased but not changed in direction.

(iii) The force diminishes.

Demonstration 5.5. (a) and (b) The electrons experience a force always at right angles to their direction of motion due to the magnetic field and so they describe a circular path, the normal acceleration being $\frac{v^2}{r}$ and the force $\frac{mv^2}{r}$ where v is the speed of the electron, m the mass of the electron and r the radius of the circular path.

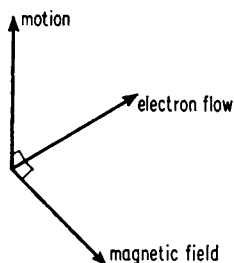
Experiment 5.6. This experiment involves assembling a horseshoe magnet from the yoke and two magnadur magnets from the kit. It is important that pupils do so with opposite poles facing one another.

(a) increased.

(b) increased.

(c) increased.

The directions of electron flow, magnetic field and motion are mutually at right angles.



Experiment 5.7. (i) A force is felt acting on the magnet either towards or away from the coil, i.e. is steady in one direction, when the supply is d.c. but the force changes direction causing vibration when the coil is supplied with a.c.

(ii) (a) The direction of the force is reversed.

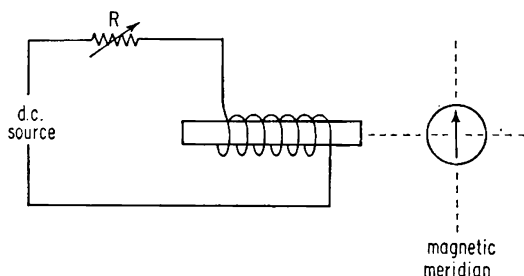
(b) The direction of the force is reversed.

(c) No change in direction of the force.

Demonstration 5.8. This is a fascinating demonstration. The trolley can be replaced by a truck on two lengths of model railway track. The vehicle must be on the level. The truck is either attracted or repelled by the coil when the latter is connected to the 12 volt supply, depending upon the direction of current flow in the coil. A force acts on the coil and this force is equal to the force acting on the magnet.

Project 5.9. A suitable scheme involves using model railway equipment similar to that used in Demonstration 5.34 on page 71 of Book Four. Two lengths of Hornby gauge O rail and two no. 50 waggons are required. The rails are joined and placed on a level surface. A 3-inch Eclipse bar magnet is attached to one of the waggons as shown in Fig. 148, page 72. A coil of about 200 turns of 26 s.w.g. P.V.C. copper wire is wound on a 1-inch diameter cardboard former about 3 inches long and is fixed to one end of the other waggon. The ends of the coil bear lightly on the live rails. The waggons are placed on the rails close to one another with the coil facing the magnet. Depending on the direction of current flow in the coil the waggons will either approach each other or move apart showing that equal forces are acting on the current-carrying coil and the magnet so illustrating Newton's Third Law.

Project 5.10. The soft iron core is clamped in an east-west direction. The current is varied by R. Start with large number of turns of wire and decrease by sliding the wire off the core.



Experiment 5.11. The needle should be parallel to the turns of the coils, i.e. the whole assembly is rotated so that, with no current flowing in the coils the needle lies parallel to the turns. The field due to the current flowing in the coil is then applied at right angles to the compass needle and is very sensitive to small currents. The instrument can be calibrated by placing an ammeter in series with the coils. The disadvantages as a current measuring instrument are that it

- (a) is insensitive to small currents,
- (b) requires to be calibrated for particular place of use,
- (c) is slow to set up,
- (d) has a non-linear scale, and
- (e) is sensitive to stray magnetic fields and materials.

Project 5.12. Attach a light paper pointer to top of soft iron rod as a pointer which can be sighted against a white cardboard background scale. It can be used on a.c. or d.c. The scale would be cramped at the lower end and it would not make a good voltmeter since its

action depends on the strength of the magnetic field due to the current flowing in the coil. It could be improved and made into a fairly good voltmeter by using a very large number of turns of fine gauge enamelled wire. The resistance would be high but so also would the ampere turns. It is the basis of a moving iron meter.

Experiment 5.13. The greatest angle of displacement of the pointer is 90° . The meter would not measure a.c. of 50 or 60 Hz as the period of the a.c. is much shorter than the natural period of the moving coil.

The coil does not move in a uniform magnetic field and so its calibration is not linear but cramped at its upper end. Shaped pole pieces and the coil rotating about a soft iron core would produce linearity of scale. A larger number of turns of wire on the coil would increase sensitivity but at the same time would add weight and/or resistance and so the coil is always a compromise. A stronger permanent magnet and finer hair 'springs' would help to increase overall sensitivity.

Experiment 5.14. The diagram illustrates a very successful yet simple d.c. motor. Commutation is made very simple but care should be taken to see that the 'brushes' press very lightly on the commutator. The motor can be made to run faster by using (1) more powerful magnets, (2) more turns of wire on the armature or (3) a higher d.c. applied voltage. The motor will run in the reverse direction if (1) the connections to the L.V. supply are reversed or (2) the polarity of the field is reversed.

The experiment shown in Fig. 124 is worth doing from the point of view of showing that at low speeds, on starting or under increased load the feed current is larger than running 'light'. It introduces the idea of back e.m.f.

Experiment 5.15. See Teacher's Guide to Book Three, page 55, Experiment 10.8.

Project 5.16, Homework. (a) Many windings so that by commutation the current flows in the loop which produces greatest torque.

(b) Very large currents flow in the coils especially at the start of rotation under heavy load and copper strips carry large currents without reaching melting point as wire would do.

Project 5.17. The edges of the tin vibrate at twice the frequency i.e. 2,000 Hz because both half cycles of the input frequency produces attraction of the 'tin'. When permanent magnets are attached the coil now 'modifies the strength of the permanent magnet and the plate vibrates at the signal frequency i.e. 1 kHz (c.f. the frequency of the ticker timer). The permanent magnet also makes it more sensitive.

The pull on the diaphragm is proportional to the square of the flux density. Hence, if B and b are the flux densities in webers/m² of the permanent magnet and the current carrying coil, the pull will vary due to changes in b from $+b$ to $-b$ during a cycle of the signal, as follows:

$$(B+b)^2 - (B-b)^2 = 4 Bb$$

Hence a really powerful permanent magnet will make the device more sensitive.

Without the permanent magnet the pull is due to $(-b)^2$ or $(+b)^2$, i.e. b^2 and as b is small the sound is small and twice the frequency or 1 octave higher than the input.

Project 5.18. Another piece of homework. The coils in the motor, the loudspeaker moving coil or field coil, and the erase, record and playback heads are all electromagnets.

Demonstration 5.19. It is essential to have a high current source. The Pye scalamp works well.

(a) Sharp deflection of the spot in one direction and (b) returns to rest position when current is steady and (c) is deflected in opposite direction to (a).

Experiment 5.20. (i) There is no indication on the meter, which is not sufficiently sensitive to read the very small currents induced in the coil attached to it.

(ii) There is now a small deflection in one direction when the primary circuit is completed and in the opposite direction when it is broken.

(iii) A substantial deflection is now observed.

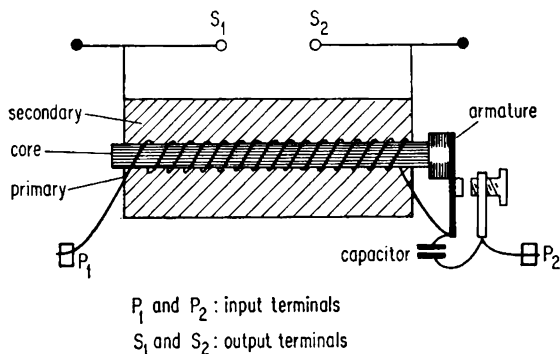
(iv) The induced e.m.f. in the secondary is increased.

Experiment 5.21. (a) and (b) The ring is repelled from the coil. On a.c. the ring is continuously repelled from the coil. The ring is undisturbed when a steady d.c. flows. Whenever a current varies as with switching d.c. on and off or with a.c. the currents induced in the ring flow so as to create a magnetic field which opposes that of the coil causing repulsion in all cases.

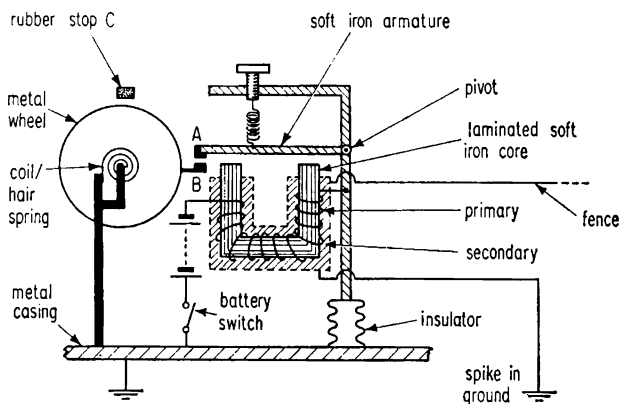
Experiment 5.22. (i) The voltage will be about 20 kV and is obtained across the secondary when the contact breaker opens. The sudden collapse of the magnetic field associated with the primary current induces a very large voltage in the secondary which consists of many thousands of turns of fine gauge wire providing a high step up ratio. The capacitor is usually 0.5–1.0 μ F and has an important function. The energy of the collapsing field will be expended in charging the capacitor. The effect will be to cause the current to fall

far more rapidly than without the capacitor and hence an extremely high voltage is produced in the secondary on 'break'. The induced e.m.f. on 'make' is so small in comparison as to be negligible.

(ii) The contact breaker in the coil ignition system is operated from the crankshaft of the engine. The contact breaker is replaced in the induction coil by an armature similar to that used in an electric bell and operated by the magnetic field created by the flow of the primary current. The circuit is shown in the following diagram:



(iii) There are several types in service and the following is a fairly popular system, operating from a 6 volt 20 AH battery.



CIRCUIT OF ELECTRIC CATTLE FENCE

When the battery switch is closed current flows from the battery through the primary coil, the armature, the contacts A and B (which are in contact due to the coil spring action), the wheel and back to the battery via the metal casing of the device. The primary current magnetises the core which pulls down the soft iron armature and

this spins contact B round against the hair spring to the rubber stop C. The primary current is interrupted when contact B leaves contact A and a high voltage is developed in the secondary winding by the sudden collapse of the magnetic field. The hair spring returns contact B to contact A in about 1 second and the process is repeated.

Experiment 5.23. (i) When the rate of change of the magnetic field through the coil is increased the e.m.f. is increased. When the number of turns in the changing field is increased the e.m.f. is increased.

Demonstration 5.24. The largest a.c. flows when the flex is rotated with its axis E-W as it is then cutting the largest number of lines of force in the earth's magnetic field.

Project 5.25. Sound waves striking the aluminium foil cause it to vibrate so cutting the magnetic lines of force and very small voltages are therefore induced between the ends of the strip. This type of microphone must be used with a sensitive amplifier.

Demonstration 5.26. (i) The demagnetised hacksaw blade does not produce an e.m.f. in the coil but when a permanent magnet is inserted into the coil an e.m.f. is induced. The vibrating blade causes the magnetic flux to change direction thus inducing an e.m.f. into the coil.

(ii) When the diaphragm vibrates near the magnet the flux is again varied and an e.m.f. is induced in the coil. It is the reluctance which is being varied in each case where an e.m.f. is produced.

Project 5.27. The two earpieces are connected by twin flex, one earpiece acting as microphone and the other as reproducer. Very close behind the diaphragm of each earpiece is a permanent horseshoe magnet having very large number of turns of fine gauge wire wound upon the pole pieces. Magnetic flux passes from the north pole of the horseshoe magnet by way of the diaphragm to the south pole. The less the air space between the poles and the diaphragm the greater will be the magnetic flux.

Sound waves arriving at the microphone cause the diaphragm to vibrate in sympathy with the compressions and rarefactions of the air. It follows that these variations of the diaphragm cause an alteration in the magnetic flux and hence produce an e.m.f. in the coils. This e.m.f. causes a current to flow along the line to the reproducer where the current causes a variation in the magnetic flux which varies the attraction between the magnet and the diaphragm. Thus the diaphragm at the reproducer copies the motion of the diaphragm at the microphone and so reproduces the sounds.

Project 5.28. Fully explained in the text.

Project 5.29. The magnet, in falling into the coil, induces an e.m.f. which increases until it is wholly within the coil when it becomes steady and decreases on leaving the coil. The energy to drive the current through the resistor is derived from the loss of potential energy as the magnet passes through the coil. The acceleration of the magnet will be altered as it passes through the coil because the current flows in the coil in such a direction as to produce an opposing magnetic field to that of the magnet and so slow it down. (Lenz law).

Experiment 5.30. (i) The output is pulsating d.c. The output (a) increases with increase of speed of rotation and (b) decreases as the strength of the magnetic field is reduced.

(ii) The output is a.c.

Demonstration 5.31. When the bulb is switched off the engine speeds up as it is no longer supplying energy to light the bulb. When the dynamo supplies current the magnetic field set up in the armature windings opposes rotation.

Experiment 5.32. The current is high when the switch is closed but quickly falls to a low value when the motor runs freely off load. When it drives a load at reduced speed the current increases above the free running value but less than the initial 'switch on' current. The current is high on switching on due to the high current which flows through the armature at rest. As soon as rotation starts a back e.m.f. is created in the armature which limits the current taken from the battery. When a load is applied the motor runs more slowly, the back e.m.f. is reduced and the current supplied by the battery increases.

Project 5.33. No comment needed.

Demonstration 5.34. The truck is pushed out when the battery is switched on showing that the original induced current flowed in such a direction as to produce a magnetic field in opposition to the permanent magnet. The induced current tends to reduce the speed of the approaching waggon, and it opposes the motion causing it.

Experiment 5.35. (a) Use a compass needle to find the direction of the field lines. The force opposes the motion of the conductor.

(b) The poles X and Y are S and N poles respectively as the magnet moves towards the coil. Y repels the approaching magnet. When the magnet is pulled away X and Y are N and S respectively and the magnet is attracted to the coil.

Experiment 5.36. Short circuiting the terminals quickly damps out the oscillation due to the induced currents which can now flow in the coil producing opposing magnetic fields. Oscillations decay in amplitude much more slowly when the coil is not short circuited.

Project 5.37. The coil may consist of 30 turns of 26 swg enamelled copper wire wound on a cork 2.5 cm long and 1.5 cm diameter. When the end of the coils are not joined the coil spins freely between the poles of the magnet. An e.m.f. is generated in the coil but no current can flow to produce an opposing magnetic field. When the ends of the coil are connected then the induced current flows so as to produce an opposing magnetic field to that of the magnet and the motion is very quickly arrested.

Experiment 5.38. The ring attempts to follow the direction of movement of the ticonal magnet. An e.m.f. is induced in the ring by the moving magnet and the current which flows in the ring produces a magnetic field which opposes that of the ticonal magnet causing repulsion. The ring moves in the same direction as the ticonal magnet. An aluminium ring is used as it is light and non-magnetic. An iron ring would not give the same results as it is magnetic and would always be attracted to the magnet. The eddy current effect, although present, would be masked by the magnetic effect.

When the ring is moved towards the suspended magnet the e.m.f. produced in the ring creates a magnetic field which opposes that of the magnet which is therefore repelled.

There is no movement of the ring when there is a gap in it as no current flows to produce an opposing magnetic field.

Experiment 5.39. (a) The penny stops spinning when the magnet is brought up.

(b) The e.m.f. produced in the aluminium disc produces a current which creates a magnetic field in opposition to the field of the horse-shoe magnets. The aluminium disc thus falls more slowly than it would under gravity alone.

(c) The spinning disc slows down and stops when the magnet is brought up. When the magnet is rotated under the disc the disc starts to rotate in the same direction as the magnet.

The rotating magnetic field below the conducting ring will induce an e.m.f. in the ring. The current which flows in the ring produces a magnetic field which reacts with that of the magnet and causes the ring to rotate with a speed slightly less than the speed of rotation of the magnetic field. If the ring turned against a hair spring on its axle the amount of turning would be a measure of the speed of rotation of the magnet. This is the principle of some motor car speedometers.

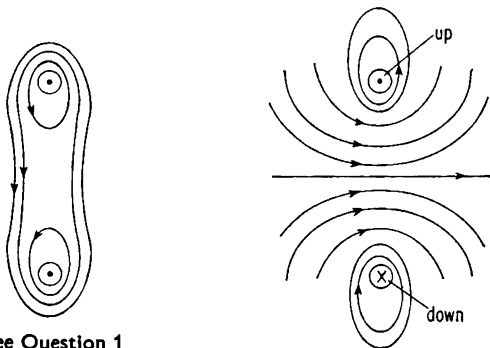
Demonstration 5.40. The bulb in series with the rheostat lights up first. Current and voltage are in phase in a purely resistive circuit. The 1,200 turn coil generates a back e.m.f. when current starts to flow in it. This back e.m.f. reduces the current drawn from the battery and there is a delay before the bulb in series with the coil reaches full brilliance. When the core is removed the inductance of the coil is greatly reduced and, in consequence, the back e.m.f. is reduced, and the bulbs appear to light simultaneously.

Experiment 5.41. It is better to use at least 80 turns in the coil. When 1 volt d.c. is applied to the coil the neon does not 'strike'. Due to the inductance of the coil the current slowly rises to a maximum value determined by the resistance of the coil. When the circuit is broken the magnetic field associated with the current suddenly collapses and induces momentarily a large e.m.f. in the coil which causes the neon to 'strike'. Do not use the switch in the power supply. The switch must be in the output circuit.

Experiment 5.42. With the coil from Experiment 5.41 in series with the bulb and the 2 V a.c. supply the bulb burns dimly. When half the turns are removed from the core the brightness is increased due to the lower inductance (i). With all the wire removed from the core the bulb turns at full brilliance as the inductance of the circuit has been reduced to an extremely low value.

The presence of inductance in an a.c. circuit reduces the current in the circuit by generating a back e.m.f. It is better to use an inductor in an a.c. circuit to reduce the current in the circuit than a resistor because the latter reduces the current by dissipating some of the electrical energy as heat. The inductor reduces the power factor of the circuit.

Experiment 5.43. The oscillations of the solid pendulum are rapidly damped out due to circulating eddy currents induced in the solid metal pendulum when it moves through the magnetic field. These



See Question 1

currents produce magnetic fields which oppose the magnetic field of the magnet.

When the pendulum bob is made of strips as shown the eddy currents are greatly reduced and oscillations diminish in amplitude much more slowly.

Magnetic materials are unsuitable for the pendulum bob. Metals which have high specific resistances are most suitable.

ANSWERS TO QUESTIONS

1. (a) attract.
(b) repel.
(c) repel.
(d) attract.
2. Yes.
3. There is an equal and opposite force acting on the field.
4. The resistance of the coil is independent of the deflection.
5. No.
6. Two only.
7. Any two being given, the third may be obtained by Ohm's Law, e.g.
f.s.d. current and R gives f.s.d. voltage.
f.s.d. voltage and R gives f.s.d. current.
f.s.d. current and f.s.d. voltage gives the resistance R .
8. Low.
9. Ammeters are placed in series with the circuit and should have a low resistance to produce the least change in the current in the circuit.
10. Less.
11. This low value of shunt is often obtained by using a length of resistance wire, or a number of wires in parallel, or a short thick strip of metal.
12. Too great.
13. Reduce the length of the shunt wire or fit another in parallel with it.
14. (a) $R = \frac{0.1}{0.49} = 0.2 \Omega$.
(d) $R = \frac{0.1}{9.99} = 0.01 \Omega$.
15. F.S.D. (voltage) = $100 \times 0.001 = 0.1$ volt.
(a) $R = \frac{0.1}{0.999} = 0.1 \Omega$.
(b) $R = \frac{0.1}{24.999} = 0.004 \Omega$.
Connect shunts of these values.

16. Low.

17. Connect in parallel with a standard meter.

18. (a) $R = \frac{99.9}{0.01} = 9,990 \Omega$ (10 k Ω) in series.

(b) (i) $R = \frac{24.9}{0.001} = 24,900 \Omega$ (25 k Ω) in series.

(ii) $R = \frac{199.9}{0.001} = 199,900 \Omega$ (200 k Ω) in series.

19. F.S.D. (current) $= \frac{0.002}{50} = 40 \mu\text{A}$.

(a) $R = \frac{49.998}{0.00004} = 1.25 \text{ M}\Omega$ in series.

(b) $R = \frac{0.002}{4.99996} = 0.0004 \Omega$ in parallel.

20. A—0.576 mA C—10.05 volts
B—10.1 mA D—100.05 volts

In the 1968 printing of Book Four, the resistor values have been changed:

A 125 Ω , giving 0.5 mA f.s.d.

B 5.05 Ω , giving 10 mA f.s.d.

C 99.5 k Ω , giving 10 V f.s.d.

D 999.5 k Ω , giving 100 V f.s.d.

21. Moving iron meter requires greater current for operation than the moving coil meter and this produces a larger voltage drop across the internal resistance of the battery.

22. (a) 2,000 Ω (2 k Ω).

(b) 100 volts.

(c) 115 V.

(d) 118 V.

N.B. If an instrument has a basic movement of 1 mA and is designed to have an f.s.d. as a voltmeter of n volts the current will be 1 mA and the voltmeter resistance (i.e. meter + series multiplier) will be $\frac{n}{0.001}$ ohms, i.e. $1,000n$ ohms. Such a voltmeter is said to have a resistance of 1,000 ohms per volt.

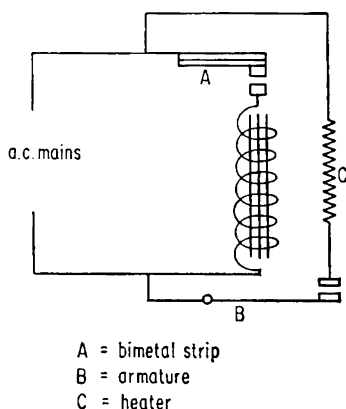
23. Extractor fans and hair driers (30 watts); Food mixer (180 watts); Sewing Machine (80 watts); Record player (40 watts); Handyman's drill (475 watts); Electric clock (5 watts); Washing Machine (360 watts); Spin Drier (240 watts); Vacuum Cleaner (340 watts). This is a good homework question. These are steady wattages for average sized machines but it would be an interesting exercise for pupils to find out. It would help to relate watts to work done by the particular machine and to its cost of running.

24. 50 Hz a.c. is fed to the coil or solenoid which creates a magnetic

field the polarity of which changes 50 times per second. The ends of the steel strip change polarity 50 times per second. If a permanent magnet is placed around the mild steel strip it will be attracted first towards one pole and then the other in sympathy with the 50 Hz input.

25. Relay control of the starter motor makes it possible to use short stout leads from the car battery to the starter motor and so reduce losses. If no relay were used the full starter current would flow through the switch on the dashboard and the switch and its leads would have to be very heavy duty types. A relatively small current flows in the relay coil circuit and the magnetic field created by the solenoid of the relay moves the armature which closes large area contacts so completing a circuit of battery and motor with short thick leads.

26.



The relay isolates the high current-carrying heater circuit from the bimetal strip which then need only carry the small current necessary to operate the relay.

27. (1) true. (3) false.
 (2) true. (4) true.
28. (a), (b) and (c) increased.
29. (a) Vertically upwards or downwards parallel to and between the faces of magnets rapidly.
 (b) In any direction in a plane parallel to the table, i.e. the wire moving parallel to the magnetic field.
30. This would be true only on switching on but the value of the current will fall rapidly as the back e.m.f. in the armature, generated by the rotation, reduces the feed current.
31. Disconnect the armature from the supply and short circuit the armature. The large induced armature current will produce an

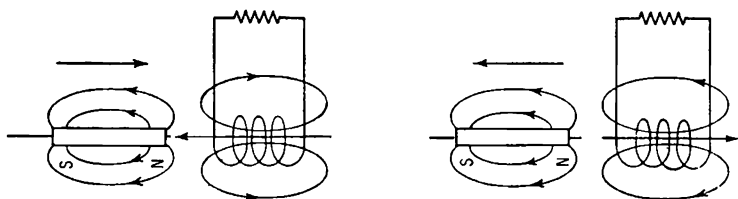
intense magnetic field which will oppose that of the motor field coils and cause braking.

32. Energy would not be conserved but generated.

33. The Conservation of Energy is one of our universal laws. We cannot find any machine in which energy will, of itself, produce more energy than is put into it and so energy must be consumed as fast as it is generated otherwise from a small input energy eventually infinite energy would be generated.

34. When the motor is starting up a large armature current flows governed by the resistance of the winding which is very low. When the armature rotates faster a larger back e.m.f. is induced which opposes the applied e.m.f. in accordance with Lenz's Law and so the feed current is reduced to a small value. Increasing the load makes the motor do more work which slows it down, the back e.m.f. falls and the feed current rises. Thus more energy must be put in to do the extra work.

35.



Winding the coils clockwise or counter clockwise makes no difference to the polarity of the magnetic field but the current in the circuit would be reversed.

36. Usually an aluminium former. Eddy currents induced in the former in accordance with Lenz's Law damp down oscillations of the pointer. This is known as eddy-current damping.

37. (a) An inductive current carrying circuit is suddenly broken and the collapsing magnetic field tends to maintain the original current which arcs across the gap.

(b) Another highly inductive circuit is broken.

38. No current will be observed although a p.d. will exist from top to bottom of mast (because an equal and opposing e.m.f. is induced in the wires to the meter). If the connections to the meter were magnetically screened a current would flow.

6 Electrons in Space — Thermionics

(pp. 78–92)

Introduction

Opportunities are afforded in this chapter to give pupils some idea of how cathode ray oscilloscope works, and the kind of circuit which lies behind each control and its effect upon the trace. All the demonstrations using Teltron tubes mentioned, particularly type 525 work extremely well and are very helpful. The thermionic diode as a rectifier is adequately covered at pupil level by Experiments 6.4, 6.5 and 6.6. The triode as an amplifier is covered by Demonstrations 6.9 and 6.10. If the triode Teltron tube 521 is not available then the principle of the triode can be shown as a pupil experiment using a circuit described at the appropriate point.

The section on TV is only for the more able if time permits.

Attention is drawn to Project 6.17. The construction of this amplifier (Fig. 212) either as a project, or in the science club or workshop is recommended. This cheap amplifier can be powered from a labpack and has many applications in the physics course, as an amplifier of sound, an oscilloscope preamplifier and as a modulator of transmitters in Chapter 10.

Experimental Work

Demonstration 6.1. This experiment illustrates the Hallwachs phenomenon later known as the photoelectric effect. When ultra-violet light falls on a negatively charged-zinc plate the latter rapidly loses its negative charge, but if the plate be positively charged there is no loss of charge. Electrons are expelled by the ultra-violet light from the zinc surface and consequently are repelled from the negatively charged plate. Photons of white light have insufficient energy to cause any effect on a negatively charged zinc plate.

Demonstration 6.2. A $50\mu\text{A}$ meter can be used instead of the galvo-amplifier. With the filament heated by 6.3 V a.c. a current of 10–16 μA flows. When heated by 6 V d.c. 6 μA flows when the anode is connected to the negative side of the filament and 50 μA when on the positive side. Current flows in the same direction always when the filament is heated and, since a larger current flows when the anode is at positive potential the charge carriers are likely to be negative.

Demonstration 6.3. Charge the electroscope either from an H.V. power pack or by induction from a charged cellulose acetate rod. Make the connection from the cap of the G.L.E. to the anode first, then charge it and finally heat the filament. When the plate is negative the leaves remain deflected but when the plate is positive it is rapidly discharged on heating the filament.

Experiment 6.4. Valve type EA50 is also called 6D1, or SD61. When this valve is heated and no anode-cathode potential is applied but anode is connected through a sensitive meter a current of about $150\ \mu\text{A}$ can be observed. This is the Edison or shot effect shown in Demonstration 6.2. When the anode is 3 volts positive with respect to cathode a current of about 12 mA is observed. Reversing the battery reduces the current to zero. *N.B.* This valve is rated at 50 volts maximum on the anode at a current of 5 mA.

A more modern valve readily obtainable from old TV sets is the EB91 (alternative types 6AL5, CV140, D77, DD6, 6D2). This is a double diode also with 6.3 V heater but the maximum anode voltage is 150 V at 9 mA.

Demonstration 6.5. (i) (a) Switch 2 closed applies H.T. (400 V) only and no current flow is shown by the meter due to the cold cathode not 'boiling off' electrons and negative potential on the anode.

(b) The cathode heats up when both switches are closed but, with a negative voltage on the anode no current flows in the anode cathode circuit.

(ii) When both switches are closed the anode current rises and steadies when the cathode has reached its operating temperature. The charge carriers are leaving the hot filament and are negatively charged.

(iii) The anode current falls with falling anode potential.

Fig. 180: From left to right the meters read:

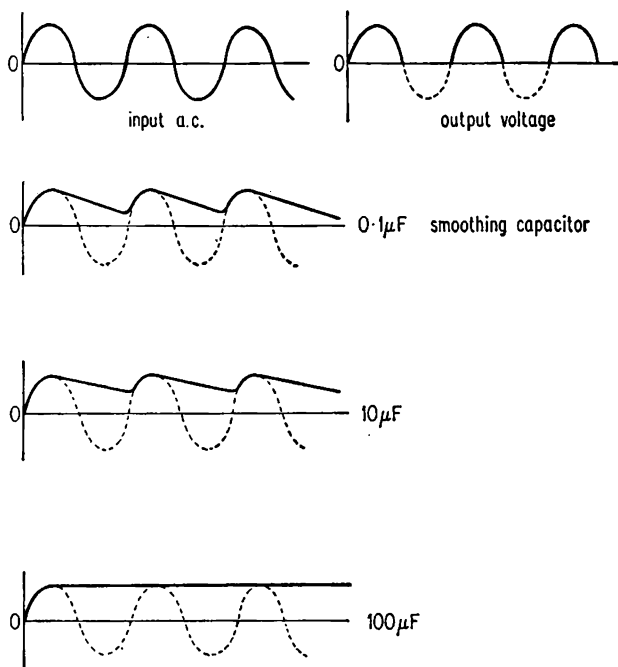
Filament voltage or current.

Anode voltage.

Anode current.

Experiments 6.6 and 6.7. (i) This is half wave rectification.

(ii) The degree of smoothing to give a steady d.c. output from the rectified output is increased by using larger reservoir capacitors but decreased by drawing more current through the load resistor, i.e. by using lower values of load resistor.



See Experiments 6.6 and 6.7

Demonstration 6.8. Well worth doing. The current is diminished and reduce to zero because the electrons streaming from cathode to anode are deflected by the magnetic field and fewer are captured by the anode.

Demonstration 6.9. (i) (a) About 0.2 mA.

(b) Zero.

(c) About 0.5 mA.

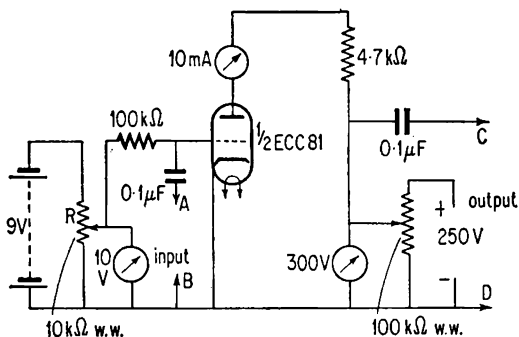
(ii) For example, 120 V change in anode voltage gives a change in anode current equal to a 6 V change in grid voltage.

(iii) Greater when connected to the filament than on open circuit. Electrons falling on the grid charge the grid negatively and so the anode current falls. Connection from grid to filament allows this charge to leak away and the anode current is greater.

Demonstration 6.10. The a.c. input signal is reproduced and amplified by the triode. The anode current develops a much larger voltage across the $1\text{ M}\Omega$ anode load resistor.

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Here is a pupil experiment using a commercial double triode valve type ECC81.



Alternating voltages can be applied between A and B and the output observed on the C.R.O. between C and D. A microphone can be connected to A and B and 'speech' observed on the C.R.O. Variation of R will show that grid voltage requires proper adjustment for maximum undistorted output.

Demonstration 6.11. (a) A very convincing demonstration. The deflection increases as the p.d. between the plates is increased. The beam is deflected downwards when the lower plate is made positive. When the magnet deflects the beam upwards the lines of force are coming straight out of the paper, i.e. the south pole of the magnet is placed against the side of the tube facing the fluorescent screen.

(b) (iii) Increase of H.T. increases K.E. of electrons because their velocity is increased by the greater potential difference through which they are accelerated.

Demonstration 6.12. It is best to feed this circuit from a labpack, with a variable high tension output.

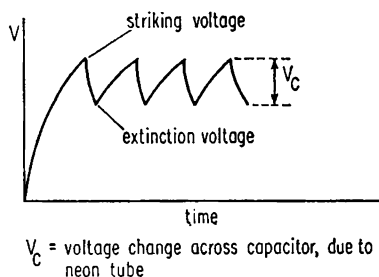
(i) If instead of a 2 MΩ fixed resistor a 2 MΩ potentiometer wired as a rheostat is used then the T.B. controls of a C.R.O. can be demonstrated.

(a) Increasing C gives a slower flashing rate.

(b) Decreasing R gives a faster flashing rate.

(ii) It is not absolutely essential to use a long persistence tube. Switch off the internal T.B. of S51E C.R.O. and connect the junction of the resistor and capacitor to X (terminal at rear of S51E) and the other side of the capacitor to E on C.R.O. (The earthing systems of both power pack and C.R.O. must not be crossed.) It is not a good time base as it is non-linear because the voltage across the capacitor

risks exponentially when it is charging. The neon ionises at its striking voltage and begins to discharge the capacitor but the discharge is not complete. It will depend on the oscilloscope used in conjunction with this circuit whether the amplitude is sufficient to give a trace which will traverse the C.R.O. screen completely.



Model 6.13. Very easily constructed and worth the effort.

Experiment 6.14. This is an important pupil experiment. (i) The spot will be deflected by 3 and 4.5 cm (or divisions) on the graticule respectively in the opposite direction. The 1 volt a.c. gives a vertical line of 2.8 cm approx. (i.e. 1.4 divisions above and below the 'no input' spot). The 2 volt a.c. gives 5.6 cm deflection (2.8 cm above and below 'no input' spot). *N.B.* 1 volt a.c. has a peak value of 1.4 volts i.e. 1 volt a.c. is the Root Mean Square Value whilst the C.R.O. registers the peak a.c. value.

(ii) (a) The peak value of the a.c. will coincide with the displacements above and a sinusoidal wave form will be displayed. The d.c. value will give a straight line which will fall short of the same a.c. peak value, i.e. it will be 0.7 or $\frac{\sqrt{2}}{2}$ of the equivalent a.c. peak value.

(b) Because speech is not a repetitive waveform it cannot be synchronised on the C.R.O. The tuning fork gives a pure sinusoidal waveform. A single tone from a musical instrument will give a regular repetitive waveform which will show evidence of harmonics.

(iii) Feed small a.c. voltage at mains frequency to C.R.O. and adjust time base to give, say 5 complete cycles. Now connect oscillator to C.R.O. and adjust the oscillator to obtain 1 cycle (10 Hz), 2 cycles (20 Hz), 3 cycles (30 Hz) . . . 8 cycles (80 Hz).

Project 6.15. The newspaper photograph normally is made up from the density of black dots on a white background, i.e. it is 'grainy' all over. Use a lens to view any picture in Book Four. One should be

careful however that the newspaper photograph is not a 'radio-picture' or 'picture by wire' (facsimile) which is built up like a television picture but over an appreciable period of time and is therefore useless as a method of transmitting a moving scene.

Demonstration 6.16. An interesting experiment on timing and triggering of the C.R.O. See also note on triggering adjustment in Demonstration 10.5 (i).

Project 6.17. Valve type ECL82 can also be used. The amplifier can be powered from a labpack with smoothed H.T. output. In the construction of high gain audio amplifiers it is essential to keep the lead to the grid of the first stage very short (less than 1 cm) otherwise use screened cable from the input socket to the potentiometer (volume control) and also from the potentiometer wiper to the grid. The screening is 'earthed' to the chassis on which the amplifier is built. This is a protection against instability and hum.

ANSWERS TO QUESTIONS

1. Positive.
2. Negative.
3. Photo—from Greek 'photos' meaning light.
Therm—from Greek 'therme' meaning heat.
4. The higher the frequency of the electromagnetic radiation the greater is the 'photon' or quantum of energy associated with it.
5. Negative charges are more likely.
6. The filament is a metallic conductor in which electrons are moving and being given kinetic energy by the hot filament and so electrons are 'boiled off' some having sufficient energy to escape from the space charge cloud and reach the plate.
7. Positive.
8. $R = \frac{3 \text{ V}}{0.003 \text{ A}} = 1,000 \Omega \text{ or } 1 \text{ k}\Omega.$
'R' is omitted from Fig. 194 in the first printing of Book Four.
9. The alternative name for this capacitor. is 'decoupling' capacitor. It removes or by-passes the alternating or signal component of the anode-cathode current and in so doing prevents negative feedback. This capacitor ensures a steady bias potential on the cathode determined by the mean anode current, i.e. anode current under 'no signal' conditions. In the sense that the capacitor maintains a steady bias potential despite the alternating voltages it may be said to 'smooth'.
10. (a) Half a cycle is displayed.
(b) 4 cycles are displayed.

11. There are two time base frequency controls:
- (a) a coarse control which involves switching in different values of capacitance.
 - (b) a fine control which varies the size of the charging resistor, i.e. the $2\text{ M}\Omega$ resistor in Fig. 201.
12. (i) Downwards towards B. } Assuming one is observing
 (ii) To the right towards D. } the screen of the C.R.T. from
 (iii) To the right towards D. } the front (as suggested in the
 (iv) Downwards towards B. } 1968 printing of Book Four).
13. (a) Particles because the kinetic energy ($\frac{1}{2}mv^2$) acquired is used to produce fluorescence on impact with the C.R.T. screen.
- (b) Negatively charged because, in the C.R.T. they are accelerated towards positive potentials.
- N.B.* In the case of oscilloscopes the final anode is at 'earth', zero or chassis potential and the cathode is made highly negative (around -2 or -3 kV). This is to keep strong electric fields away from the deflecting X and Y plates.

14. $500eV \equiv 500 \times 1.6 \times 10^{-19}$ joules.

$$\equiv 8 \times 10^{-17} \text{ joules.}$$

$$\frac{1}{2}mv^2 = 8 \times 10^{-17}$$

$$v = \sqrt{\left(\frac{8 \times 10^{-17} \times 2}{9 \times 10^{-31}}\right)}$$

$$= 1.3 \times 10^7 \text{ m/s.}$$

The energy is released mainly as heat so that the valve must be capable of dissipating this heat effectively. Large transmitting valves have large blackened anodes, or anodes fitted with cooling fins or anodes cooled by water.

15. Total charge per second $= 1.8 \times 10^{17} \times 1.6 \times 10^{-19}$ coulombs/s
 $= 29 \text{ mA.}$

$$\text{Power} = 400 \times 29 \times 10^{-3} \text{ watts}$$

$$= 11.5 \text{ watts.}$$

7 Electrons in Semiconductors— Transistors (pp. 93–102)

Introduction

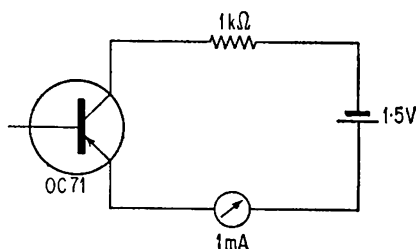
It is left to teachers to decide how much semiconductor theory ought to be attempted at 'O' grade. The very important Hall Effect as it applies to semiconductors is not required at 'O' grade. The diode as a rectifier is dealt with in Chapter 8. The transistor as a current amplifier only is necessary at 'O' grade and this work is covered by Experiments 7.6, 7.7, 7.8 and 7.9. No calculations or graphical work are needed.

The Optional Extras are only for the most able pupils. Project 7.12 might well be left to the section on Oscillations (Chapter 9). Project 7.11 is worth while for the science club or workshop as it has useful applications later in the course.

Experiments and Demonstrations

Experiment 7.1. (a) The resistance falls due to more electrons in valence band acquiring sufficient energy to leave the covalent bond and pass into the conduction band. Thus hole-electron pairs are created by heat alone. The bulb shows this by glowing more brightly.

(b) 50°C in case of the OC71 is hot enough, as higher temperatures may lead to collapse of the crystal lattice. Increasing conductivity of the OC71 can be shown by the following circuit.



Experiment 7.2. The ORP12 cell is connected to the ohmmeter range of a multimeter.

An OCP71 phototransistor in the circuit of 7.1 (b) above works very well.

Demonstration 7.3. The n-type and p-type pieces of germanium which are mounted in perspex for the Hall Effect experiment described and shown in Demonstration 7.5 are very suitable for this

experiment but should not be heated by a match. They can be used in conjunction with a mirror galvanometer (as used in Demonstration 3.1 adjusted to its 15μ range and with its spot centred on the scale, or another sensitive centre-zero microammeter.

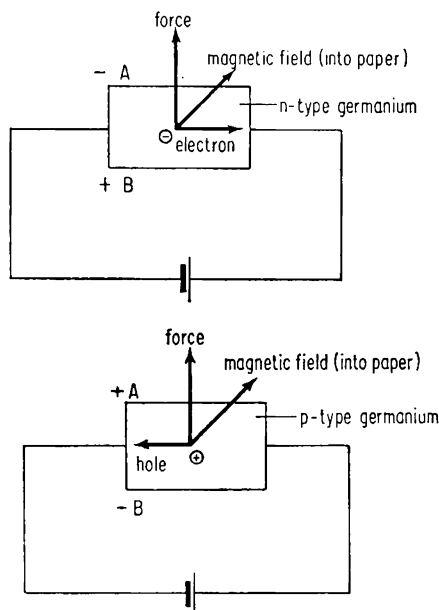
The germanium slice, embedded in the perspex, is heated by pressing a finger over one end of the slice or by lowering the perspex plate edgewise into a basin of warm water so that only one end of the slice is immersed. The meter will show a current after a few moments. If the same germanium slice is heated at the other end the meter will be deflected in the opposite direction.

(i) In the case of *n*-type germanium the majority charge carriers are electrons and they move through the slice away from the heated end.

(ii) In the case of *p*-type germanium the majority charge carriers are holes and they move through the slice away from the heated end.

Model 7.4. This is a very useful preliminary to Demonstration 7.5. There is a voltage between the plates and the upper plate is negative as it is collecting electrons from the beam. The same magnetic field would deflect positive charges flowing in the opposite direction upwards also. The upper plate would then be positively charged with respect to the lower.

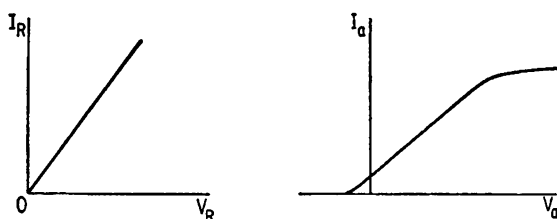
Demonstration 7.5. The apparatus shown in Fig. 225 should be made up permanently on a board as the balancing potentiometers are



rather fragile. The meter must be sensitive and a $500\text{--}0\text{--}500\ \mu\text{A}$ meter also works very well. If a double pole double throw (D.P.D.T.) switch is included the meter can be switched from n -type to p -type with minimum delay. The Hall Effect depends on the fact that charges moving at right angles to a magnetic field experience a force and a voltage is developed across the material through which the charges are flowing. This voltage is called the Hall voltage.

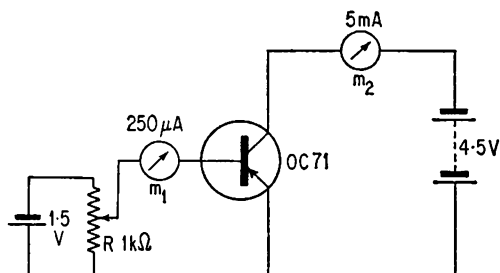
In the diagrams the magnetic field is directed into the paper and, in the case of the n -type germanium, the polarity of side A is negative with respect to side B showing that a negative charge is being deflected towards side A. In the case of p -type germanium the Hall voltage is reversed and side A is positive showing that the charge carriers are positive. Thus the majority charge carriers in n -type germanium are electrons and in p -type germanium are holes.

Experiment 7.6. The current through the resistor is linear, that through the diode is non-linear.



Demonstration 7.7. If a transistor is to be opened great care must be taken. Grip the glass envelope near the connecting wires so that the glass cracks. Carefully pull off the glass in the direction away from the wires. The paste covering the transistor is water resistant but can be brushed off with a fine brush dipped in organic solvent. Viewed through a magnifying glass the emitter bead can be seen to be smaller than the collector bead and separated from it by a very thin slice of base material.

Experiment 7.8. If a graph is not desired then the paragraph beginning 'In practice it is found . . .' on page 99 can be translated into a practical circuit as follows:



Small changes in the base emitter current, shown on m_1 ($250 \mu\text{A}$), are caused by rotation of R ($10 \text{ k}\Omega$). These small changes will produce corresponding but much larger changes in the emitter collector circuit as shown by m_2 (5 mA).

Experiment 7.9. If a $2.2 \text{ k}\Omega$ resistor is inserted in place of H.I. phones, voltages developed across this resistor can be applied to the input terminals of a C.R.O. and the amazing amplification can be displayed. This circuit corresponds to the triode valve circuit seen in Demonstration 6.10.

Project 7.10. One for the science club.

Project 7.11. This amplifier could well be made in the workshop as it has many applications one of which is as an oscilloscope pre-amplifier in which case the output transformer is removed and a $2.2 \text{ k}\Omega$ resistor is made the load of the OC72. Voltages developed across this resistor are applied to the C.R.O. input terminals.

Project 7.12. This one could well be postponed until oscillations have been studied. If oscillations do not commence immediately reverse connections to one coil winding. The frequency of the oscillations can be varied by changing the value of the $0.05 \mu\text{F}$ capacitor in the tuned circuit. The frequency is increased by substituting smaller values of capacitor or decreased by putting capacitors in parallel with the $0.05 \mu\text{F}$ capacitor.

Project 7.13. Another science club project useful on open days showing transistors as switches or the basis of a binary counter.

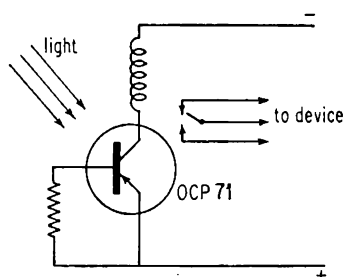
Project 7.14. This one is for the very able pupil only.

ANSWERS TO QUESTIONS

1. Transistors are crystal valves not requiring heat to produce charge carriers as in thermionic valves. Electrons and holes are available for conduction in transistors at room temperature and it is only necessary to connect the supplies of power (usually dry batteries) and the set 'comes on'.

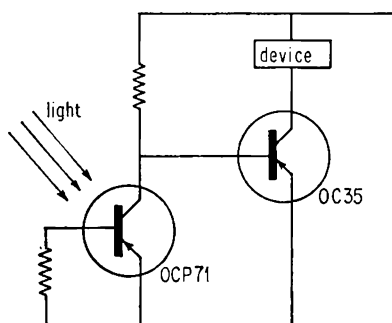
2. R_1 and R_2 form a potential divider across the battery supply and their values determine the potential applied between emitter and base and is given by $\frac{R_2}{R_1 + R_2} \times E_B$ neglecting the effect of the very small base emitter current. (E_B = battery potential.) R_1 and R_2 should bring the transistor to its working point. R_3 is fitted in the

emitter lead so that, as the temperature of the transistor rises and it becomes more conductive due to the production (thermally) of hole-electron pairs in the base material of the transistor, the potential so developed in R_3 counters the voltage across R_2 and so lowers the base current thus maintaining the current gain of the transistor. Small changes in base-emitter current due to the incoming a.c. signal produce correspondingly large changes in the emitter-collector current. The capacitor C_2 is made large enough (commonly $100\ \mu\text{F}$) to present a very low impedance path to the a.c. signal which otherwise would pass through R_3 so producing negative feedback as described in the last paragraph. Capacitor C_1 allows the a.c. component of the input signal to reach the base of the transistor but it is



a block to any d.c. component present in the input signal which would alter the base bias voltage. Capacitor C_2 allows the amplified a.c. output signal to be passed to the next stage without that stage altering the emitter-collector voltage of the transistor by shunting it.

3. The large expensive rheostat R_1 has to carry the total current drawn by the circuit and must have an appropriate wattage rating. The wiper of R_2 can vary the voltage applied and therefore the current which can flow in the base-emitter circuit. The base-emitter current controls the current which can flow in the emitter-collector circuit which is in series with the circuit and the supply. Thus the transistor performs the same function as R_1 .



Where a relay is used to control a device, as in Fig. 26 the circuit of the device is separated from the circuit actuating the relay. This is important where the device carries high voltages or high frequency currents.

The use of a transistor to replace the relay, as in Fig. 27, does not isolate the control circuit from the controlled circuit. The relay contacts carry the current to operate the device in Fig. 26 whereas the power transistor carries the current to operate the device in Fig. 27.

8 Swinging Electrons (pp. 103–126)

Introduction

The effects of alternating currents have traditionally been taught in a very mathematical manner. The topic can, with advantage, be treated in a more experimental way, with the pupils doing most of the experiments. If time does not permit the performance of all the experiments and demonstrations described in this chapter then it is the latter which should be missed out. The following comments are offered as a guide to their selection.

Experiments 8.1, 8.2 and 8.3 could well be done together, setting up the apparatus at 'stations'.

Demonstration 8.5 should not be missed out as it leads to a profitable discussion of the need for standardisation of frequency and voltage in a public electricity supply produced by rotating machinery. Experiment 8.8 is an important one. The term 'effective volts' is to be preferred to 'r.m.s. volts' at this stage.

Experiments 8.10 and 8.11 together with Demonstration 8.14 will cover the bare essentials of the work on transformers.

Demonstration 8.16 and Project 8.19 provide links between laboratory work and the practical applications. Such opportunities for teaching the work-a-day use of electrical principles should not be missed.

Experiment 8.21 is a necessary preliminary to the use of the slow a.c. generator in later experiments in this and the following chapter.

Questions 25, 26 and 27 are more difficult than the rest and their solutions will require careful explanation. All the others are suitable for home exercises.

The 'Optional Extras' (page 118 et seq.) offer more difficult topics which will interest the very able pupils or may be tackled at post O-grade.

Experimental Work

Experiment 8.1. The deflection is small (about 0.1 mA for 5 turns on the coil) but is quite definite and its direction can be seen clearly.

Experiment 8.2. (i) This is most easily arranged if an iron weight is used. Any coil of a few hundred turns will show the effect if connected to a milliammeter. Similarly any coil having a few thousand turns will do if connected to the C.R.O. See also Fig. 332 of Book Two.

(ii) The tuning fork will be magnetised strongly enough by stroking it once or twice with a powerful magnet.

Experiment 8.3. No comment is needed.

Experiment 8.4. If the gramophone (record player?) is one of the autochange type the central column will make it awkward to set up alternative (a). The second, (b), scheme is then easier and works very well. No plasticine is needed if the turntable happens to be a steel one.

Experiments 8.5 and 8.6. No comment is needed.

Experiment 8.7. Connect the source of unknown frequency to the oscilloscope vertical, Y, input terminals and adjust the controls on the C.R.O. to obtain a stationary pattern of, say, three complete cycles to ten graticule divisions. Disconnect the source from the C.R.O. and in its place connect the calibrated Signal Generator. Do not alter any of the C.R.O. control settings. Adjust the Signal Generator frequency, and amplitude if necessary, to get the same number of complete cycles as before. Read off the frequency from the Signal Generator scale.

Note that if you use a power pack with a full wave rectifier the ripple frequency will be 100 Hz.

Experiment 8.8. The d.c. must be very smooth so use a battery. The ripple in the output of a power pack will make it impossible to compare the two cases. A rheostat, about 13 ohms maximum, will do instead of the low frequency a.c. generator.

It is quite easy to obtain a result of 0.7 volts d.c. using the eye alone to compare brightnesses. The exposure meter is a nice but unnecessary refinement.

Experiment 8.9. It is instructive to have pupils measure the separate voltages first. Note that no two power supplies will give exactly equal outputs and so their out-of-phase sum will not be zero.

Experiment 8.10. Pupils should check for themselves that the frequency of the secondary output is the same as that of the input to the primary. They are often confused and mistaken about this.

Experiment 8.11. Adjusting the C-cores to give the minimum primary current, i.e. the minimum magnetising current, ensures that the transformer is working at the maximum efficiency possible with that particular design.

Demonstration 8.12. The term 'load' is used in a somewhat confused

way in the literature of electronics and electricity. It is sometimes used to mean the current flowing from the output (e.g. of a transformer or amplifier) and sometimes to mean the resistance (the 'load resistor') connected across the output. In this instance 'no load' means no current, an open circuit.

These demonstrations may be performed, though not so elegantly, with any of the demountable transformer sets which are available.

Demonstration 8.13. Resist the temptation to immerse the primary in water as well!

Demonstration 8.14. The efficiency of such small transformers will be of the order of 80 %. Very large transformers such as those used in the National Grid have efficiencies much higher than this, up to around 99 %.

Joulemeters and kilowatt-hour meters should always be mounted with their dials vertical as their rotors will only run freely in that position. An inscription will be found on the front of every kWh meter indicating the number of revolutions of the rotor (disc) per kilowatt-hour. As $1 \text{ kWh} = 3,600,000 \text{ J}$ one can then easily calculate the number of joules per revolution.

Demonstration 8.15. (i) The most efficient transformer is the one made up with the laminated yoke and laminated U-core. With no yoke at all the reluctance of the magnetic circuit is high and so the flux is small. The eddy currents set up in the solid iron yoke generate a lot of heat and therefore a lot of energy is 'wasted'.

When the secondary is open circuited the efficiency is zero since there is then no power output at all. If however a voltmeter is placed across the secondary winding it is no longer open-circuited strictly speaking and the efficiency will be found to be very high—90 % or more.

(ii) This is not a very efficient transformer. A 'real' transformer is more efficient because there is a well designed magnetic circuit which ensures that practically all the flux generated by the primary links the secondary winding.

Demonstration 8.16. The bulb lights very dimly or not at all when placed at the end of the long wires. When the two transformers are put in circuit the bulb lights brilliantly. The loss of energy in the lines is reduced (by reducing the current in the lines) and this more than makes up for the small losses introduced by the transformers.

Demonstration 8.17. In order to demonstrate the melting of a nail one must make sure that the resistance of the whole secondary circuit is as low as possible—to allow the maximum current to flow.

This means that the nail must be clean and that the connections to it should be screwed up very tightly.

Project 8.18. No comment needed.

Project 8.19. One advantage of the ring circuit is that there are two parallel paths for the current to flow from the transformer to any one bulb. In practice this means that one can use lighter cabling.

Plugs are usually supplied with 13 ampere fuses. It is a common, and dangerous, practice to use them as supplied without considering what appliances they are connected to. Pupils should be taught to choose the fuse of the correct rating for a particular job. The range of ratings is being reduced and it is likely that only 3 A and 13 A fuses will be widely available in the future. This makes the choice easier.

Experiment 8.20. (i) The pattern is the same as Fig. 317.

(ii) See Fig. 312.

Experiment 8.21. The oscilloscope used must have a 'd.c. input'. If the normal 'a.c. input' is used the capacitor in the input circuit will offer a decreasing impedance as the frequency is increased—and the amplitude displayed on the screen will increase.

Experiment 8.22. The capacitor stores both charge and energy.

Demonstration 8.23. D.C. does not flow through a capacitor. Charge flows on to and then off the plates.

Experiment 8.24. (i) This will show that capacitive reactance decreases with increasing capacitance.

(ii) and (iii). No calculation of reactances (or capacitances) in series and parallel are required but the pupil will note that capacitors in parallel offer less opposition than either one, while capacitors in series offer more opposition than either does separately. Combining this result with that of (i) above should lead to the conclusion that capacitors in parallel have a greater capacitance than a single capacitor, while those connected in series have less. This reasoning will enable them to answer the un-numbered questions at the foot of page 115.

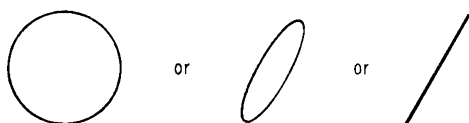
Experiment 8.25. The opposition offered by the coil depends on both the number of turns and the arrangement of the core(s). A core with a low reluctance (no air gaps) will give a larger inductive effect and hence a larger opposition to a.c.

Experiment 8.26. There should be no difficulty in seeing that resistance does not change with frequency; that capacitive reactance decreases with increase of frequency; and that inductive reactance increases with increase of frequency.

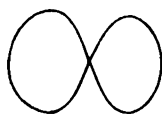
This effect can also be shown by using an audio frequency signal generator as the variable frequency source—but beware of taking the frequency too high. Any coil has distributed self-capacitance between the turns and at some frequency this will resonate with the inductance; at still higher frequencies the coil will behave like a capacitor! It is better to stick to the slow a.c. generator and avoid having to make complicated explanations for the odd behaviour of the coil. If this method is adopted one should use a good multimeter (such as AVO, Taylor or Selectest) as these are reasonably accurate up to about 2 kHz.

Demonstration 8.27. The voltmeter used should be a good one but the demonstration can be done with a meter having a sensitivity as low as 1,000 ohms/volt. The large electrolytic capacitor *must* be connected the correct way, i.e. with its positive terminal connected to the positive pole of the battery.

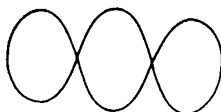
Demonstration 8.28.



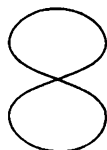
frequency ratio 1:1



frequency ratio 1:2



frequency ratio 1:3



frequency ratio 2:1

Experiment 8.29. To perform this, and all other experiments involving low frequency a.c. and a C.R.O., the C.R.O. used must have a 'd.c. input' facility.

(i) One must arrange the connections to the C.R.O. so that the current and voltage appear in phase (reversing the connections will make them appear to be in antiphase).

(ii) The current leads the voltage by 90° .

(iii) The current lags the voltage by 90° .

Do not be tempted to use a larger inductance. Any poor contact between the rotor and resistance element of the slow a.c. generator causing a momentary interruption in the current will result in the inducing of very large back e.m.f.'s across the coil. These may well be large enough to damage the input circuit of the C.R.O.

Demonstration 8.30. This is an alternative to 8.29.

Demonstration 8.31. The warning note also applies to most of the 'electronic switches' which are designed to enable one to display two signals simultaneously on a single-beam C.R.O.

Experiment 8.32. The gain control on the C.R.O. should be set to give a vertical line 5 cm (5 graticule divisions) in length for 1 V a.c. input. The time base should be switched off. Once this has been set the gain control must not be touched again but the vertical, Y, shift control may be used to set the bottom of the line on a graticule line in order to make the measurements easier.

(i) The sum of the voltages across C and R, or L and R, is not equal to 1 V—because of the phase difference.

(ii) The phasor diagram will yield a result for the value of the input voltage, 1 V, to within 4% if the pupils are careful in estimating the lengths of the lines on the C.R.O. screen.

(iii) The resistance of the coil will make the value of the input voltage calculated from the phasor diagram less than the correct 1 volt.

(iv) This usually causes excited comment from the class as one of the measured voltages will be greater than the input voltage. The difference between V_L and V_C will be very nearly equal to 1 V. The discrepancy is again due to the resistance of the coil.

Demonstration 8.33. The 4 microfarad capacitor must be a paper type, not an electrolytic capacitor. It must have an a.c. working voltage of not less than 250 V (be sure that this is quoted a.c. working voltage and not the d.c. one as this will be different). Failure to use the correct type of component could result in blown fuses, or an exploding electrolytic capacitor.

Demonstration 8.34. (i) The energy transferred as measured by the Joulemeter and by the product VIt should agree to within about 3%.

(ii) The capacitor used must be able to withstand an a.c. ripple current of at least 300 mA. Choose a Radiospares 47 microfarad 450 V Negative Can electrolytic capacitor, or a Hunts 50 microfarad 350 V type L38/1 (available from Electronics, Edinburgh Way, Harlow, Essex), or any other capacitor with a working voltage of 200 V or more and capable of withstanding a ripple current of 300 mA or more.

(iii) The particular coil, capacitor and resistance have been chosen to offer approximately equal impedances to the a.c.

It is well to note that the rotating discs on some Joulemeters will drift around by as much as 10 joule divisions in 100 seconds with no load connected to its output terminals. This should be checked and a correction made to the measured values to allow for this error.

Experiment 8.35. The waveform is obviously that of a full-wave rectifier. To make the point clearer the pupils should switch the C.R.O. input to 'd.c.', examine the a.c. output from the power supply and then the d.c. output. The waveform will be seen to be unidirectional—all lying above (or below) the centre line.

Experiment 8.36. The C.R.O. input should be set to 'd.c.' before starting the experiment.

(i) As larger and larger capacitors are used the waveform becomes smoother and the average voltage more nearly equal to the peak value of the unrectified alternating voltage.

(ii) The waveform is smoothed out because the capacitor charges up to the peak a.c. value—and there is no discharge path (except through the input resistance of the C.R.O.).

(iii) The full-wave rectifier gives the smoother output (with about half the ripple amplitude) since the capacitor has less time, 0.01 s as against 0.02 s, during which to discharge through the 600 ohm resistor before being charged again.

Demonstration 8.37. At these low frequencies the 'd.c.' input to the C.R.O. must be used. The Telequipment S51E C.R.O. can be supplied with the P7 medium (long) persistence tube in place of the normal one at the same price. The trace persists for a few seconds after the spot has moved on and this enables one to see more clearly the waveforms traced by a slowly moving spot.

An 8 microfarad capacitor connected across the resistor will just about discharge completely before the next charging half-cycle. With a 2,000 microfarad capacitor the voltage across the 100 kilohms (and the capacitor) is very nearly constant with scarcely any perceptible drop as the capacitor discharges.

(a) The larger the capacitor the more charge it will store for a given p.d. and hence the charging current will be greater. The initial discharge current, through the 100 kilohm resistor, is limited by the resistor and this current can be supplied by the larger capacitors, for 0.01 seconds, with only a very small drop in the p.d. across the capacitor. To look at it in another way, the quantity of charge that flows during the 0.01 seconds discharge half-cycle is, for a large capacitor, only a very small fraction of the total charge stored.

(b) See the comment on Experiment 8.36 above.

Experiment 8.38. As the core is inserted the inductance of the coil is increased and so its reactance increases. This causes a larger fraction of the 1 volt supply to appear across the coil and so the voltage across the capacitor and resistor falls.

Experiment 8.39. (i) At 50 Hz the reactance of the coil is fairly high (a few thousand ohms) and that of the capacitor fairly low (about 14 ohms) so that most of the alternating voltage is dropped across the coil. Once the capacitor is charged all the direct voltage will appear across it.

(ii) Such filter circuits are commonly used to separate a.c. and d.c. components of a complex waveform, and also, by suitable choice of values for L and C, for separating alternating voltages of different frequencies. The current through a half-wave or full-wave rectifier may be analysed into a direct component with superimposed alternating components. Inductors are often included in 'smoothing circuits' to separate these components and help to produce a steady d.c. output.

ANSWERS TO QUESTIONS AND PROBLEMS

1. This is the manner in which most ticker-timers work (not the one made by Griffin and George Ltd.). The strip is magnetised along its length by the field due to the current in the coil. The direction of its magnetisation is reversed in each successive half-cycle of the a.c. supply. Hence the free end is alternately attracted by the N and then the S pole of the permanent magnet. Thus it will oscillate at the supply frequency.

Start the ticker-timer and pull a tape through for, say, 5 seconds. The dots are counted and the number divided by 5. This is not very accurate since one probably did not start the stop watch (to time the 5 seconds) at the instant a dot was made, and the dots tend to be rather bunched together and indistinct at the start.

2. 3.0 volts. 0 volts.

3. The direction of movement of the pointer depends on the direction of the field due to the current in the moving coil, and this

depends on the direction of the current. Anyway, unless the frequency is very low, the coil and pointer cannot 'follow' the current and the pointer remains at zero.

4. V_p = effective (r.m.s.) voltage across the primary winding.
 V_s = effective (r.m.s.) voltage across the secondary winding.
 I_p = effective (r.m.s.) current flowing in primary circuit.
 I_s = effective (r.m.s.) current flowing in secondary circuit.
 t_p = number of turns on the primary winding.
 t_s = number of turns on the secondary winding.

The voltage ratio is most nearly equal to the turns ratio when the secondary current is zero.

The current ratio is most nearly equal to the inverse turns ratio when the secondary current is very large. In this case the primary current is large also and the magnetising current is only a small part of it.

5. 120 ohms.
6. 6 ohms.
7. 114 ohms.

8. The question should really refer to the rate of input of energy (the power), as it does in the 1968 printing of Book Four. The power input to the circuit = 480 watts.

9. See the answer to question 8. The power input to the bulb is 24 watts. The remaining energy is dissipated as heat produced in the resistor.

$$10. \text{The efficiency} = \frac{\text{Power output}}{\text{Power input}} = 24/480 = 1/20 = 5\%.$$

However, if one considers the useful output to be the light energy output the overall efficiency is much less; probably about 5% of 5%, or 0.25%.

11. A step-down ratio of 20 to 1. i.e. $t_p/t_s = 20$.
12. (i) A step-down ratio of 20 to 1.
 (ii) A step-down ratio of 120 to 1.
 (iii) A step-down ratio of 30 to 1.
 (iv) A step-up ratio of 2.5 to 1.

13. The factor to emphasise here is the current flowing in the line. This is, obviously, related to the voltage between the ends of each line but the current is, in practice, determined by the power to be transmitted.

14. Reduced.

15. Less with the transformers in circuit, since the current is then less.

16. (a) $W = V \times I = I \times R \times I = 2$ watts.
 (b) $W = 100 \times 2 \times 100 = 20,000$ watts.
17. (a) $I = W/V = 10$ A.
 (b) Power lost = $10 \times 10 \times 10 = 1,000$ watts.

(c) $I = 1$ ampere.

(d) Power lost $= 1 \times 10 \times 1 = 10$ watts.

18. $t_s = 50$. The primary current $= 0.05$ A approx. It would be rather larger than this because of the magnetising current.

19. Use a step-down transformer with, say, 1,000 turns on the primary and 25 turns on the secondary.

A rough rule-of-thumb guide to the number of turns to be used is that $A \times N = 8$, where A = area of cross section of the core in square inches and N = the number of turns per volt.

The button is put in the low voltage circuit to lessen the risk of shock and to avoid arcing across the switch contacts.

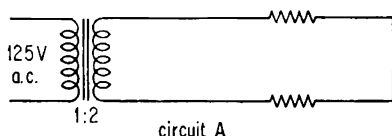
20. 300–0–300 V means that it is a centre-tapped winding giving 300 V r.m.s. across each half, i.e. 600 V across the whole. Hence $t_s = 3,600$ turns.

For the 6 V secondary $t_s = 36$ turns.

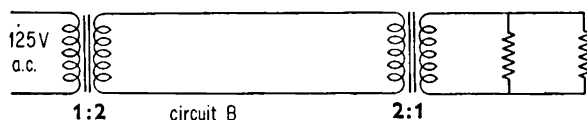
For the 5 V secondary $t_s = 30$ turns.

These answers are based on the assumption that the efficiency is 100%.

21. Max. power $= 125 \times 20 = 2,500$ W.



circuit A



circuit B

He would require a transformer with a turns ratio of 2 to 1 connected as in circuit A. Alternatively he could use two such transformers as in circuit B. Note that in either case the currents in the leads on the low voltage sides of the transformers is 40 A (approx.).

22. (a) Power loss $= 3,200$ W.

Total resistance $= 200$ ohms.

So Total volts drop $= 8,000$ V.

So voltage available $= 267,000$ V.

(b) We now have 50 V drop over a total line resistance of 200 ohms, hence max. current $= 0.25$ A.

23. No.

24. The faster the alternator is rotated the greater is the rate of cutting magnetic field lines and hence the greater the induced e.m.f. (supply voltage).

25. During the charging time the back e.m.f. (opposing voltage due to the accumulated charge) increases. As the frequency of charging (and discharging) rises the time available for the back e.m.f. to grow is reduced; there is less opposition to the flow of charge; the reactance is less.

26. It will increase.

27. Reduce the current.

28. It should!

29. Nil.

30. They are not in the same direction.

31. Y_1 .

32. From B to R.

33. R.

34. 2 V a.c.

35. There has to be a heater supply and this means another winding on the transformer—as in Fig. 314. The heat that must be dissipated by the valve heater may be a disadvantage in some circumstances.

36. A.

37. An acceptable answer would be that the necessity of supplying heater current to each valve makes the wiring rather complex. Since only two of the cathodes are at the same potential three separate heater windings are required.

In fact such circuits are to be preferred for outputs in excess of about 1,500 volts as the peak inverse voltage across each rectifier is only half what it would be in the full wave circuit of Fig. 312.

38. X is positive.

9 Oscillations (pp. 127–149)

Introduction

The notions of frequency, period and amplitude will have been dealt with in earlier work (see Book Two, Chapter 4) while studying waves. We have now to build on these and add the further concepts of damping, resonance and resonant frequency. Throughout this study the teacher should be continually drawing the attention of the class to the interchange of energy that occurs in any oscillatory system, and to the ways in which energy is lost from the system (damping). 'Energy' is one of the concepts basic to this whole O-grade course.

This is where 'seeing is believing'—and understanding. The emphasis must be on pupil experiment wherever possible, although a number of demonstrations must, of necessity, be performed by the teacher assisted by one or more members of the class.

Experiment 9.1 is obligatory. The pupils must see for themselves, think for themselves and, in the first instance, draw their own conclusions. These conclusions may have to be modified after class discussion at the end of the practical work.

Experiments 9.2, 9.3 and Demonstration 9.4 may be omitted without much loss, but only if time is pressing.

Demonstration 9.6 is an excellent one and very simple to set up. The apparatus for 9.7 is easily constructed in the science workshop and is well worth the effort.

Demonstration 9.11 of damped, slow, electrical oscillations is so vivid and so fascinating that it must not be left out. Taken together with 9.13 it serves to illustrate all the basic ideas involved in understanding electrical oscillations.

A choice may have to be made between Experiments 9.15, 9.16 on one hand and 9.17, 9.18, on the grounds of apparatus shortage. Pupils should do one pair even if the other pair have to be demonstrated.

Experimental Work

Experiment 9.1. These experiments lend themselves admirably to the use of 'Stations' technique. A selection of the systems illustrated is set up in the laboratory. The class is divided into, say, six groups and, after preliminary discussion and instruction, the groups are set to work, one group to each system. They are told to conduct the investigation on the lines indicated in the introduction to the

experimental work (top of page 128). Allow them 15 to 20 minutes to each system. Each group should investigate some three or four and then the class is brought together to discuss their work—and to bring out the main points, viz. that in each case the frequency depends on the magnitude of the oscillating mass (inertia) and on the restoring force, and that the damping, which does not affect the frequency, is due to energy loss through friction or air resistance.

Some of the experiments could well be grouped together, e.g. (j) and (k), (l) and (m).

The system illustrated in Fig. 339 is incorporated in the Philip Harris circular motion apparatus.

Experiment 9.2. The weight of the water causes it to fall, expanding the air in the flask and reducing its pressure. Eventually the difference in pressure between the atmosphere and the air in the flask is great enough to push the water back up the tube. Air will then rush into the flask, the pressure difference will be reduced and the weight of the water again causes it to fall. This sequence will repeat until the water level is at the top end of the tube.

Experiment 9.3. The only other pendulum with the same length, and therefore the same natural frequency, will swing with greater and greater amplitude (while the amplitude of the 'red' pendulum will decrease). The rest hardly move at all. The red ball should be massive compared with the other pendulum bobs and the horizontal string should not be stretched too tightly. The arrangement is known as 'Barton's Pendulums'.

Energy is being transferred through the horizontal string at the right frequency for the pendulum which has the same length as the red one.

Demonstration 9.4. The shaft must rotate very slowly—at about 1 revolution per second. See the note on Demonstration 9.8 (c) below.

Demonstration 9.5. (a) and (c) It is interesting to note that the various resonant frequencies of such flat blades as are used here are not simple integral multiples of the fundamental frequency.

(b) Use loaded blades and do not make them too short. If the natural frequency is too high one has great difficulty in vibrating one's hand fast enough. Blades 20, 25 and 30 cm long are suitable.

(c) Do not use more than 50 cm or the fundamental may be below the lowest frequency of the Signal Generator.

Demonstration 9.6. It is instructive to measure the frequency of rotation of the motor at maximum amplitude and then to disconnect

the drive and measure the natural frequency of the loaded blade. They are, of course, the same. When 'tuning' for maximum amplitude the speed of the motor should be varied very slowly.

If the loading of the hacksaw blade is by small magnets their position may be altered to change the natural frequency. In this way the blade can be 'tuned' to the fixed, motor frequency.

Demonstration 9.7. This can be performed with the Philip Harris circular motion apparatus.

Demonstration 9.8. (a) The output of the Signal Generator should not be too great when one is examining the fundamental. If the vibrator is driven too hard the cord will vibrate in various overtone modes as well and this confuses the picture. Good results will be obtained with about 1 m of cord loaded with 400 gf and driven by an Advance J2 Signal Generator set to 20 V output.

The graph of amplitude against frequency is as shown in Fig 39. on page 143.

Increasing the tension will raise the frequency. Increasing the length will lower the frequency.

If the wire is driven at a frequency which is an integral multiple of the fundamental frequency one sees a number of loops corresponding to the multiplying factor, i.e. if the wire is driven at a frequency nf_0 the number of loops will be simply n .

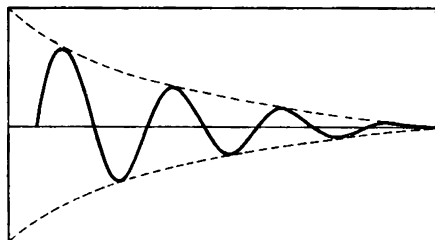
(b) This is much the best arrangement for demonstrating harmonics. Up to seven loops can be quite clearly seen. It is interesting to use a strobe lamp to point out the nodes and antinodes—and to see the snake-like undulations of the cord.

(c) Both depend on the fact that limiting friction is greater than sliding. The moving bow or shaft drags the oscillating wire or pendulum to one side until the friction is not great enough and sliding begins.

Demonstration 9.9. (a) If one uses about 80 cm of shirring elastic stretched to about 1 m the fundamental frequency will be of the order of 25 Hz. The direction of vibration of the vibrator has to be carefully adjusted to keep transverse vibrations to a minimum. As in Demonstration 9.8 the drive has to be kept down to avoid exciting the harmonics when one wishes to examine the fundamental mode.

Demonstration 9.10. A sensitive crystal microphone will give an output of the order of 1 V when the loudspeaker is driven from an Advance J2 Signal Generator with its output set to 20 V. If an oscilloscope is used it is advisable to start by setting the gain to give a vertical line (time base off) 10 graticule divisions long at resonance.

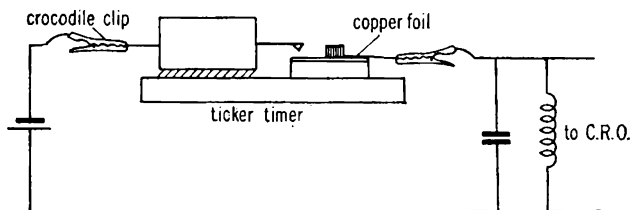
Demonstration 9.11. This is a fascinating demonstration of a damped oscillation. It might be thought to be more convincing if no switch is used. The capacitor is first connected to the battery only—in order to charge it. The charged capacitor is then moved over and connectde to the coil and meter. The C.R.O. should be set to give its slowest time-base. If the capacitor is connected to the coil just as the spot begins its movement across the screen the whole of the damped oscillation will be displayed.



(i) The frequency of oscillation increases when the capacitance is decreased.

(ii) The frequency of oscillation increases when the inductance is decreased.

Demonstration 9.12. The following alternative arrangement is suggested as being easier to explain to a young class.



The ticker-timer is modified by fastening a piece of copper foil in place of the carbon-paper disc so that the vibrator makes contact with it on its downward stroke. The capacitor is then alternately charged from the $1\frac{1}{2}$ V cell and discharged through the coil. The same coil (note that it has no core) and capacitor values as shown in Fig. 376 are suitable. This method applies a true 'square wave' to the capacitor whereas the method outlined in the text applies the 'saw-tooth' waveform of the sweep output. The saw-tooth distorts the damped wave slightly and it will be seen to be 'peaky'.

Demonstration 9.13. The resonant frequency is very low and one needs to rotate the low frequency generator very slowly indeed to produce alternations at frequencies below the resonant frequency.

The frequency for maximum current readings will be found to be the same as the frequency of the damped oscillations of Demonstration 9.11—provided that the same coil-capacitor combination is used.

The driving frequency that produces these maximum current readings also gives the maximum voltage across the capacitor.

Demonstration 9.14. Any small triode will function in this circuit. The waveform will be nearly sinusoidal if the capacitance is large (greater than 5 microfarads) and the H.T. voltage is just sufficient to maintain oscillations. Greater H.T. voltages will give a peaky waveform.

Experiment 9.15. The coil should be on two, clamped C-cores. There will be a minimum current at one particular frequency.

Experiment 9.16. There will be a maximum current at one particular frequency. This frequency will be equal to that found in Experiment 9.15.

Experiment 9.17. At one particular setting of the cores the current will be a minimum. This is an example of 'tuning' a circuit to a given frequency. In radio frequency circuits it is more usual to vary the capacitance. It is not possible to construct variable capacitors of reasonable physical size with maximum capacitances greater than about 0.001 microfarads. So, at lower frequencies the inductance is more easily varied. Since the parallel combination has a maximum impedance at resonance it is sometimes called a 'rejector circuit'.

Experiment 9.18. At one particular frequency the current will be a maximum (impedance is then minimum). This is an 'acceptor circuit'.

If the C.R.O.'s used have earthed input terminals these must be connected together at the junction of the coil and capacitor. The time bases should be switched off so that the heights of the vertical lines are a measure of the two voltages. The gain controls should be set to give a line of, say, two graticule divisions long when the C.R.O.'s are connected directly to the 1 V a.c. supply. It will be found that at resonance the voltages across the coil and capacitor are equal and that they are greater than the supply voltage.

- (i) In a parallel circuit at resonance the current is a minimum.
- (ii) In a series circuit at resonance the current is a maximum.

Demonstration 9.19. (a) At resonance, when the input current is a minimum, the currents in the capacitive and inductive arms are equal but in antiphase—and the bulbs in the two arms are equally bright.

If the tuned circuit had no resistance at all the oscillations once started would go on, undamped, for ever. The currents in the capacitive and inductive arms would be equal and in antiphase—and the supply current would be zero. However, all 'real' circuits have resistance (we have deliberately introduced some by including the bulbs) and the energy dissipated as heat in this resistance has to be supplied by the source; otherwise the oscillations would die out. The power dissipation is measured by the product of p.d. and current for the particular resistance element being considered. Since, at resonance, most of the supply voltage is across the tuned circuit and the supply current is low little power is lost in the lamp in the input circuit. The currents in the two branches can be quite large and hence most of the power supplied by the source is dissipated in these two bulbs. Do not be misled into thinking in terms of currents alone—one might then think it very odd that the 'input' lamp is the dimmest.

Below resonance the current in the inductive arm is the greater; above resonance the current in the capacitive arm is the greater.

(b) The 4 microfarad capacitor must have an a.c. working voltage of at least 250 V.

This experiment must not on any account be performed by pupils as there are exposed terminals at mains voltage.

Demonstration 9.20. (a) At one particular position of the core the current will be a maximum. This is the resonance condition.

(b) At the resonant frequency (f_0) the current will be a maximum; the reactances of the two components will be equal; the voltages across them will be equal and these voltages will be greater than the input voltage.

(i) Below f_0 the voltage across the capacitor is the greater.

(ii) Above f_0 the voltage across the inductor is the greater.

The graph of current against frequency will have the general shape of the curve in Fig. 395.

N.B. The voltages across the coil and capacitor would only be exactly equal if the coil had no resistance. Since it must have some resistance it is more correct to state that the vector sum of the voltages across the two components will, at resonance, be equal to the p.d. needed to drive the current through the resistance and also equal to the supply voltage.

Demonstration 9.21. The Fractional Horsepower Motor, N150, plus its Gearbox, N152/1, makes an acceptable substitute for the gramophone turntable. It has the added advantage that the speed of the motor can be controlled by altering the armature current.

Demonstration 9.23. Any loudspeaker of practically any impedance will operate in this circuit.

Reducing the capacitance will increase the frequency of oscillation and the pitch of the note.

Demonstration 9.24. The bulb glows most brightly when the circuit constants, L and C , of the left-hand circuit of Fig. 400 are adjusted so that the resonant frequency is equal to the oscillator frequency. The anode current of the oscillator will be seen to rise as the left-hand circuit is tuned to resonance. This is because more energy is being drawn from the power supply—the energy dissipated in heating the bulb filament.

ANSWERS TO QUESTIONS AND PROBLEMS

1. No. For the frequency to be the same the restoring force would have to be proportional to the mass. This is not so in this case.

2. He could stand further back—nearer to the point of support.

3. Less. For the same reason as given in answer to question 1 above. The restoring force is partly gravitational and partly due to muscle power. It is not proportional to the mass.

4. Yes.

5. These are the speeds at which the engine vibrations occur at the natural frequency of the door, heater and exhaust pipe respectively.

6. In time with the natural swing (vibration) of the branch, i.e. pull down as the branch swings down and let go as it swings up.

7. At the same frequency as that at which it swings on its own.

8. Yes. One half, one third, etc., of the natural frequency of the swing.

9. It *can* be done at various frequencies but one is to be preferred, i.e. the natural frequency of swing of the arm and discus.

10. This is because the thrower can build up a large swing more easily if he times his effort to coincide with the natural period of arm plus discus.

11. The pendulum is swinging to the right during the time that the current is building up to its maximum value and the average current is therefore smaller during this part of the swing than during the swing back to the left. The force exerted on the iron pendulum is thus smaller as it moves to the right than as it moves to the left.

12. (a) Surface waves on water, a wave-pulse on a long rope, electromagnetic waves.

(b) Stationary waves on a stretched string, standing waves produced by a reflector placed to reflect 3 cm radio waves at normal incidence.

(c) Sound waves, longitudinal waves on a long 'slinky'.

(d) Sound waves in an organ pipe or other wind instrument.

13. (a) The ticker-timer method, i.e. place the blade in a solenoid, fed from a low voltage a.c. supply, so that one end is clamped and the other end is free to move between the poles of a permanent magnet; use the electric bell principle.
- (b) A variable speed motor driving a crank which is connected to the oscillating mass by a rubber band in such a way as to pull down on the mass on each downward swing.
- (c) The same sort of arrangement but with the crank revolving in a horizontal plane and driving an arm clamped to the torsion bar (or wire).
- (d) Some arrangement for tilting the curved track bodily each time the ball reaches the extremity of the track; some more sophisticated methods may employ photocells to switch on electromagnets to attract a (steel) ball at the appropriate part of the track.

The above are some suggestions to start pupils thinking—there are obviously a great number of possible alternatives.

14. (a) Rotational K.E. to strain P.E. stored in the twisted wire or rod. Damping is due to 'internal friction' and air resistance and energy is used to overcome these. This energy is finally transformed into heat.
- (b) K.E. of the moving string to P.E. of the stretched string. Damping is due to the same factors as discussed in (a).
- (c) Rotational K.E. to gravitational P.E. Damping is due to friction at the support and air resistance.

15. The (mains) driving frequency is 50 Hz. If the timer is tuned to this frequency we get the maximum amplitude of vibration. The natural frequency could be reduced by loading the vibrating strip, e.g. with a small piece of metal fixed on with sellotape.

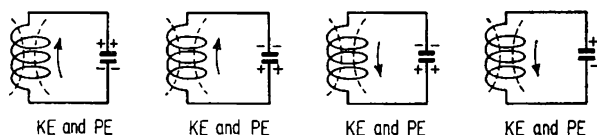
This makes a good practical problem. The compact light source (N 21) is placed so as to throw a shadow of the vibrating strip on to a piece of graph paper arranged as a screen. The amplitude of vibration is then half the width of the shadow. The timer should be driven by an audio frequency signal generator, such as the Advance J1, J2 or SG65. The frequency is varied from about 46 to 54 Hz in steps of 1 Hz and the corresponding amplitudes noted.

16. (a) Not at all.
- (b) The frequency decreases (frequency $\propto 1/\sqrt{\text{length}}$).
- (c) Practically no change. $\sin \theta = \theta$ is correct to within 5% when $\theta = 10^\circ$.
 - (i) At the centre of its swing, the lowest point of its swing.
 - (ii) Same as (i).
 - (iii) Same as (i) and (ii).
 - (iv) At the end of its swing at either side; at its highest point.

(v) Same as (iv).

It has zero acceleration at the centre of its swing; at the lowest point.

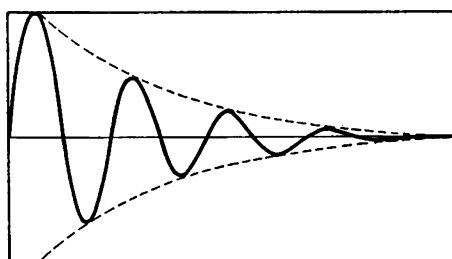
17.



18. (a) Minimum. (b) Maximum. (c) More. (d) Less.

19. (a) Maximum. (b) Maximum. (c) Minimum. (d) Less. (e) More.

20.



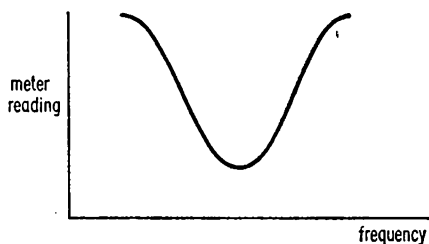
21. A capacitor. With the switch at A the total impedance of the two capacitors in series would be greater than that of the capacitor in the 'black box' alone. With the switch at C the current is greater because the capacitor in the black box together with the coil form a series circuit resonant at a frequency near to that of the supply.

22. The figure could represent either the change in current through a series circuit as the frequency is taken through resonance OR the change of impedance of a parallel circuit.

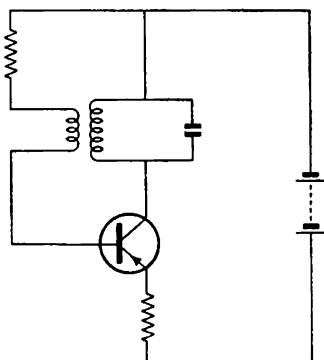
23. R_1 should be small. Energy is lost from the circuit as heat is produced in R_1 .

R_2 should be large. To prevent any energy loss from the circuit no current should be shunted through R_2 ; to minimise the loss the current through R_2 should be kept as small as possible.

24. The circuits shown in Figs. 404 and 405 are both parallel circuits and therefore both will show a minimum current at resonance.

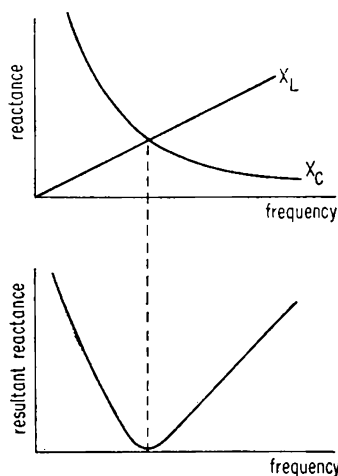


24. One needs to include a base biasing resistor to set the base current at the correct value and the small coil must be connected in the right way around to give positive feedback and so sustain oscillations. The circuit shown here, or that in Fig. 244 of Book Four, may be used.



The effect of the emitter resistor in limiting the current flowing in the emitter and collector circuits, perhaps through an increase in temperature, can be thought of in another way. Imagine that the emitter current increases; the p.d. across the emitter resistor will increase and the emitter will become more negative. Hence the base-emitter voltage will decrease; this will decrease the base current and this, in turn, will tend to decrease the collector, and so the emitter, current.

26.



The graph represents the resultant of a series circuit. It is a minimum at the resonant frequency. Since the voltages across the capacitor and the inductor are in antiphase at any frequency the resultant reactance is the difference between their separate reactances. The resonant frequency is indicated by the point at which the two reactances are equal (and opposite), i.e. at the point where the two curves cross.

10 Space Travel (pp. 150-170)

Introduction

This chapter covers the production and detection of electromagnetic waves and some of their properties. Much is demonstration because of the nature of the apparatus but, wherever possible, pupil participation should be encouraged. The 3 cm klystron equipment is a very flexible system capable of displaying in a most convincing manner the fundamental properties of electromagnetic radiation, viz. reflection, refraction, diffraction, polarisation and interference, as well as methods of conveying intelligence in the form of amplitude modulated waves.

If time permits pupils should construct the simple but effective receiver of Experiments 10.8 (a) and (b). It brings together in one device many of the physical concepts dealt with in Chapter 9.

The production of electromagnetic waves of frequencies higher than radio in the heat, light X-ray and γ -ray bands are described and some of their more important applications demonstrated.

Experimental Work

Demonstration 10.1. The loop and bulb are fitted in the inductor box permanently in this apparatus. In the case of the second tuned circuit the loop and bulb may be dispensed with and the tuned circuit connected in place of the link in the 3 cm detector equipment shown in Fig. 423. This allows the second tuned circuit to be moved away from the oscillator coil and resonance is shown by the maximum meter reading.

Demonstration 10.2.

- (i) $\lambda f = c$, where λ is wavelength in metres
f is frequency in Hertz
c is velocity of e.m. radiation, 3×10^8 m/s

$$\lambda = \frac{3 \times 10^8}{140 \times 10^6} = 2.1 \text{ m.}$$

The bulb dims when the dipole is placed at 90° to the radiating dipole since the waves are plane polarised.

Demonstration 10.3. (i) The diode in the wave guide rectifies or demodulates the a.c. set up in the dipole by the e.m. wave and the

current is passed through the m.c. meter. The energy comes from the e.m. wave.

(ii) As the receiver is moved in a horizontal plane around the transmitter the meter reading falls off rapidly on either side of the direction of propagation.

(iii) Non-conductors of electricity. (*N.B.* If a system of parallel straight conductors, half a wavelength apart is placed at right angles to the direction of propagation of plane polarised waves then the radiation will be cut off when the conductors are parallel to the electric field. In this equipment the electric field is parallel to the shorter sides of the waveguide.)

(iv) Yes. Angle of incidence is equal to the angle of reflection.

(v) The waves are doubly refracted in the same way as a light beam showing that the speed of the waves has been reduced by the prism.

(vi) Diffraction is observed by exploring the region around a single slit using the diode probe. It should be possible to detect waves bent around the edges of the slit.

(vii) Interference is also observed behind two slits using the diode probe which links up very well with the pattern produced by two dippers in a ripple tank. Radiowaves at the lower end of the M.F. band (about 200 metres) suffer quite severe interference due to ionospheric irregularities after sunset.

Demonstration 10.4. The experiment works well when other reflecting surfaces are further off. A person walking through the area of convergence of the reflectors will reflect sufficient energy to cause a significant increase in the loudspeaker signal.

Demonstration 10.5. (i) The Advance SG 65 or similar oscillator driving a telephone earpiece is suitable as a source. The transistor amplifier shown in Fig. 243, page 101 is suitable as the receiving amplifier if the output transformer is replaced by a 22 k Ω resistor and the voltages developed across it are fed to the input terminals of the C.R.O. via a 0.1 μ F capacitor. Alternatively, the valve amplifier of Project 6.17 will do if its output transformer is replaced by a 10 k Ω (2 watt) resistor and the voltages developed across it are fed via 0.1 μ F capacitors to the input of the C.R.O. A long persistence tube is really necessary. The oscillator output is turned up and fed via a key to a loudspeaker as shown in the Fig. 429. Switch the C.R.O. trigger control to 'auto', reduce the stability to the point where the trace disappears (i.e. the time base just stops) and, whilst operating the key, advance clockwise the triggering control until, on key down, only the time base is triggered off. A very short burst or signal will now trigger off the time base and produce a Y deflection

near the start and at a distance from the start. The separation is measured on the graticule from which the ceiling height may be calculated knowing the speed of the time base which may have to be checked as described in 10.5 (ii).

(ii) The oscilloscope is the S51E with its sweep output fed by coaxial cable to the input of the Unilab amplifier with its internal speaker switched off and its output fed to an external speaker. The sound pulses are picked up by the Acos type 40 or any other sensitive crystal microphone and fed to the input of the C.R.O. directly.

The valve amplifier described in Project 6.17 can be used if desired. If the output from the microphone is insufficient to give a reasonable Y deflection on the C.R.O. a transistor preamplifier will be necessary. The experiment works quite well with the S51E C.R.O. with its time base set at 1 ms but, as the stability control also affects the sweep frequency it is well not to rely upon the calibration. Calibrate the time base from a J.1 or SG65 audio oscillator without making any change in the time base speed used in the experiment. It may be better not to measure from the beginning of the trace to the signal but to move the microphone from, say, $\frac{1}{2}$ metre to $1\frac{1}{2}$ metres from the loudspeaker, measuring the change in position of the signal in centimetres on the C.R.O. graticule. *N.B.* Both 10.5 (i) and 10.5 (ii) require some time and patience to set up satisfactorily. If triggering is not automatic (i.e. not switched to 'auto') then changes of time base frequency usually necessitate readjustment of the trigger control.

Demonstration 10.6. The signal generator provides the 'carrier' the amplitude of which can be altered by rotation of the White Generator, the depth of modulation being 100% when the 100 Ω rheostat is reduced to zero resistance or shortcircuited.

Demonstration 10.7. (i) The amplifier of Project 6.17 has sufficient output to modulate the V.H.F. oscillator. Otherwise the Unilab amplifier shown in Figs. 431, 424 and 425 will suffice.

(ii) This must be a carbon microphone feeding into a microphone transformer having a step-up ratio of about 100:1. Upwards of 15 volts can be expected across the secondary when speaking closely into the microphone. This voltage modulates the self-excited oscillator. Otherwise the method described in (i) above will be satisfactory.

(iii) Again the amplifier of Project 6.17 can be used to modulate the 3 cm klystron transmitter and can be powered from the same source as the transmitter. Remove the output transformer from the amplifier and substitute a 10 k Ω (2 watt) resistor. To avoid signal short circuits the anode end of this resistor is connected by a 1 μ F

capacitor to the klystron reflector. If another amplifier is used then a second connection must be made to the klystron cathode via a $1\ \mu\text{F}$ capacitor. *N.B.* The G.P.O. do not raise any objection to the use of these types of R.F. oscillators so long as they are not in any way modulated and so long as they do not interfere with their communications. If it is desired to modulate these transmitters the advice of the G.P.O. must be sought and it is likely that an industrial licence may be required. Application should be made to the Radio Services Department, St. Martin's-le-Grand, London, E.C.1.

Demonstration 10.8. (a) If a ferrite rod is not readily available then the coil may consist of 60 turns of 24 S.W.G. d.c.c/enamelled copper wire close wound on a 4 cm diameter cardboard former and tuned by a 365 pF standard variable capacitor. Connect an aerial of about 20 metres length and at least 10 metres high. Do not forget to connect the earth wire to a good earth point such as a cold water pipe (not of the plastic variety!). Any general purpose diode such as OA70 or OA81 will do.

(b) The one transistor amplifier (OC71 or GET114) works very well and gives appreciable amplification. If the earphones are placed in a large open box the sound is greatly increased.

Project 10.9. This is the circuit of a very efficient receiver which can be run on $\frac{1}{2}$ volt from a fuel cell or from a solar cell or a U2 battery, which is interesting from an energy change point of view.

Demonstration 10.10. No comment is needed.

Demonstration 10.12. (i) The X-rays accelerate the discharge of the electroscope to which they are directed irrespective of the sign of the charge on the electroscope. This shows that the X-rays are producing a leak to earth of the sign of the charge on the leaf. The X-rays ionise the air in and around the electroscope thus producing the leakage path.

(ii) The X-rays supply sufficient extra energy to cause ionisation of the neon gas and the tube strikes and glows brightly.

(iii) A d.c. flows in the meter showing that the X-rays are producing ionisation in the chamber and therefore a small current is flowing in the chamber.

(iv) The gas in the G.M. tube is ionised by the X-rays and the charges are collected by the electrodes, and so constitute a small current which is shown on the ratemeter or scaler.

(v) The vapour particles become charged due to the X-rays and the interaction of these charged particles produce the tracks.

(vi) Dental film Phil X is also suitable in this application.

ANSWERS TO QUESTIONS

Problem 1

Time taken by sound from L.S. to travel 1 metre to trigger off the

C.R.O. time base = $\frac{1}{333}$ second.

∴ Total time taken for reflected signal from ceiling to reach C.R.O.

$$\begin{aligned} & \frac{6 \times 10}{1,000} + \frac{1}{333} \\ &= \frac{\quad}{2} \text{ s} \\ &= 0.0315 \text{ s} \end{aligned}$$

∴ Height of ceiling = 0.0315×333 metres
= 10.5 metres.

11 Spectra—The Give-away Lines

(pp. 171–178)

Introduction

Different types of spectrum are studied in Experiments and Demonstrations 11.1, 11.2, 11.3 and 11.4. The sun's spectrum is one that can't be produced to order, at least in this country, but the others can, and these experiments are of the kind which can be set up round a laboratory and examined by pupils moving from one to the next so that most of the study and discussion can be covered in one lesson.

Experiment 11.5, leading up to the diffraction grating, could be replaced, if time were short, by one of the several good loops on the subject.

As the author suggests, Project 11.6 is suitable for the enthusiastic photographer.

Experiment 11.7 is well worth doing. It is probably the easiest experiment by which a pupil working with simple apparatus can obtain a good estimate of a wavelength of light.

Experimental Work

Experiment 11.1. (i) As the current is increased, the filament changes from dull red, at which time the red end of the spectrum is visible (probably as far as green by the time enough light is being emitted) to white, when the full spectrum can be seen.

(ii) The colours transmitted by the filter are observed.

Experiment 11.2. (i), (ii), (iii) In each case a line spectrum is produced.

(iv) Line or continuous (e.g. from some street lamps) spectra are produced.

Demonstration 11.3. (a) (i) A yellow line.

(ii) A continuous spectrum with a dark line where the yellow line had been.

This is not particularly easy to demonstrate. For success, the flame must be accurately placed at the image of the filament. The flame must also be strongly yellow. The continuous spectrum must be bright.

When the various pieces of apparatus have been aligned, cut off the continuous spectrum by inserting a sheet of paper or something similar between the lamp and the flame. When the paper is removed, a dark line should be seen where previously there was a bright yellow line.

(b) A fairly weak solution is best. Potassium permanganate solution, again fairly weak, also produces an absorption spectrum.

Experiment 11.4. On no account should the sun ever be viewed directly through an optical instrument. The method suggested may be used, or the spectrum may be projected on to a screen.

Experiment 11.5. The smaller the wavelength, the greater the deviation. To decrease the wavelength, increase the frequency of vibration.

Project 11.6. No comment is needed.

Experiment 11.7. (i) In each case a number of continuous spectra is seen, on either side of a central white image of the lamp filament. The spectra become more extended and eventually overlap as the order increases (the pair of spectra nearest and on either side of the centre are called first order spectra, the next pair second order, etc.).

The greater the number of lines/mm, the greater the spread of each spectrum and the greater the deviation of each order from the centre.

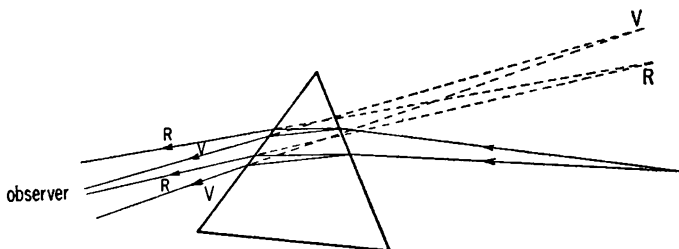
Darkness is helpful but not essential.

Ray box bulb filaments are satisfactory.

(ii) The range of wavelength in the visible spectrum is approximately 4×10^{-7} to 7×10^{-7} m. The expected values for red and blue can easily and quickly be obtained.

ANSWERS TO QUESTIONS

- (a) A single continuous spectrum is seen. If the refracting edge of the prism is pointing to the left as it is held in front of the eye, then the violet end of the spectrum is also to the left. The explanation is in the figure.



- (b) A series of continuous spectra on either side of a central white maximum is seen. In each spectrum the violet end is towards this central maximum. Red has been deviated most ($\sin \theta = n\lambda/d$).

Overlapping takes place between spectra of higher order than one.

12 Rays of Activity (pp. 179–208)

Introduction

One of the problems in teaching radioactivity to under-16-year-olds is that they are not allowed by law to use radioactive sources—apart from the very low activity sources that the manufacturers provide with diffusion cloud chambers. This restricts the experimental work that the pupils can do for themselves. It follows that we must make every effort to involve them in demonstrations by making them read the meters, time the pulses, suggest further experiments and draw their own conclusions. It also follows that Experiment 12.2 is to be preferred to Demonstration 12.1, and Experiment 12.6 to Demonstration 12.5 (even though the latter is a better analogue).

Teachers who are embarking on the teaching of this topic for the first time are advised that the d.c. amplifier has more applications than the pulse electroscope. It will detect β particles as well as α particles, cuts down the time needed to perform many experiments and may be used in the teaching of other branches of physics.

Demonstration 12.7 is not necessary if the d.c. amplifier is to be used for the rest of the work, and 12.12 may be omitted without much loss of understanding of radioactive processes.

Demonstration 12.18 is to be preferred to 12.17, if a choice has to be made.

Teachers should strive to make it clear that radioactive substances must be handled with care, in the same sensible way that one handles high voltages or strong acids. The precautions set out in the answer to question 26 are the minimum requirements for safety.

Experimental Work

Demonstration 12.1. (i) (a) The tracks are straight, (b) appear at random and (c) are of fairly definite lengths, but are not all the same length. When the needle is placed in the container of thorium carbonate and made about 600 V negative relative to the case it collects a deposit of $^{216}_{84}\text{Po}$ (Thorium A). This has a half-life of 0.2 seconds (see Fig. 498), decaying to $^{212}_{82}\text{Pb}$ (Thorium B) by emitting an α particle. This isotope of lead decays with a half-life of 10 hours by the emission of a β particle, yielding $^{212}_{83}\text{Bi}$ (Thorium C)

and $^{212}_{84}\text{Po}$ (Thorium C'). It is these last substances which emit the α particles causing the tracks to be seen in the cloud chamber. The energies of these particles are such that their *mean* ranges in air are 4.8 and 8.5 cm respectively.

Occasionally one might see a track that does not start from the needle. These are probably caused by cosmic ray particles or α particles from radon (a gas).

Experiment 12.2. The easiest way to level the chamber is to watch the way the tracks drift and adjust the level to counteract this. The tracks will have lengths of about 4 and 6 cm (the source is radium-226 and its decay products) and are produced at irregular intervals.

(ii) A few α particles will get through the very thin foil. This tells us that there are 'spaces' between the atoms of aluminium and that these atoms are packed together more closely than those in the air. The very much smaller β particles will pass through both foils.

(The numbers 12.3 and 12.4 have been omitted in error.)

Demonstration 12.5. The film is affected mostly by γ rays which do travel in straight lines to give the outline shape of the object. Some of the β particles can also penetrate to the film but many will be absorbed in the air and in the wrapping paper.

Demonstration 12.6. (i) The energy given by the flame to the air molecules raises their average speed to the point at which ion pairs are formed at some collisions between higher energy molecules. The plate of the electroscope attracts ions of opposite charge. These ions move to the plate and neutralise the charge thereon.

(ii) The energetic particles emitted by the radium, especially the relatively massive α particles, will also create ion pairs by collision with the air molecules, with the same result.

Demonstration 12.7. (i) The use of the very high resistances ($500\text{ k}\Omega = 500 \times 10^3\ \Omega$) supplied by the makers of pulse electroscopes will emphasise the sensitivity of these instruments. With an H.T. of 500 V a pulse rate of at least one pulse per second should be obtained. This corresponds roughly to a current of the order of $500/500 \times 10^3 = 10^{-9}\text{ A}$. Much slower pulse rates can be timed and so much smaller currents measured—down to 10^{-11} A .

(ii) The current between the plates is now the movement of the ions created by the action of the flame or the α particles.

Demonstration 12.8. The d.c. amplifier is a most versatile tool and has uses in the teaching of electrostatics, the measurement of resistance, capacitance and voltage (to 10 kV), the determination of pH values, as well as in the study of radioactivity. Currents of 10^{-11} A

can be recorded as a full scale deflection on a 1 mA meter, hence currents as small as 10^{-13} A can be readily detected.

Demonstration 12.9. (i) The mean range of α particles from radium is about 3.25 cm. The meter reading will go up quite sharply when the source is about 6 cm from the gauze. An estimate of the *maximum* range can be made in this way.

Distances should be measured to the milled ring in the centre of the source assembly.

The paper will cut off very nearly all the radiation, i.e. it cuts off the α particles.

Although β particles are more penetrating their specific ionisation (number of ion pairs created per centimetre) is much less than that of the more massive α particles. They cause fewer ion pairs per cm and so the ionisation current is very much less. Typical values are 600,000 ion pairs/cm for α particles and only about 300 ion pairs/cm for β particles having energies of the order of those ejected from radium, americium and strontium.

(ii) This is best done by plotting a graph of meter reading against the distance of the source from the gauze. See part (i) above.

(iii) A very small current will be detectable even when the source is beyond the maximum range of the α particles. There must be some other radiation present which is more penetrating. The aluminium sheet stops this other radiation and the reading falls to zero. We conclude that this radiation is made up of β particles.

A 100 microampere meter is useful here in place of the standard 1 mA meter.

(iv) Since the presence of the magnet affects the meter reading the particles must be charged.

Demonstration 12.10. The sheet of paper prevents any α particles entering the chamber. The meter will read zero until the magnet is held in the right position and the correct way round. β particles will then be deflected into the chamber.

Deducing the charge on the β particles is easy if the pupils have been brought up to think in terms of electron flow, as opposed to conventional (positive charge carriers) current. For users of conventional current direction Fleming's Left Hand Rule will appear to indicate that the particles should be deflected upwards when the magnet is set to give a maximum meter reading. One then has to point out that the observations will 'fit' the rule if the particles are negatively charged.

Demonstration 12.11. This is a method by which the arrival of individual particles can be detected. The particles obviously arrive at irregular intervals—emphasising the random nature of atomic events.

A spark counter will only detect α particles. A sheet of paper will stop practically all the sparks. This is a convenient way of measuring the maximum range of these α particles in air as there is quite a sharp cut off at the range limit.

Demonstration 12.12. (b) the OC202 is a silicon transistor with a very low leakage current (I_{CEO}). A germanium transistor is not recommended here.

Demonstration 12.13. (i) Place the end of the Geiger tube about 6 cm from the source. This will give an initial count rate of something less than 1,000 counts per second (the maximum rate registered by most ratemeters used in schools). The following results are typical:

Background count rate = 0.5 counts/s

Count rate with unshielded source = 950

Count rate with thick paper = 750 (α 's stopped)

Count rate with 2 mm Al = 65 (β 's stopped)

Count rate with 20 mm Pb = 11 (most γ 's stopped)

One can conclude that $^{226}_{88}\text{Ra}$ and its daughter products radiate α , β and γ rays.

(ii) In order to detect α particles from $^{241}_{95}\text{Am}$ at all the source must be placed very close to the end of the thin-window Geiger tube; about 3 mm away.

The following results are typical:

Source	Radiation	Separation of source and end of Geiger tube	Type of screening	Count rate Counts/s
$^{241}_{95}\text{Am}$ 0.125 μC	α	3 mm	Nil	58
			Thick paper	2.8
			2 mm Al	1.2
$^{90}_{38}\text{Sr}$ 0.125 μC	β	3 mm	Nil	210
			Thick paper	200
			2 mm Al	7
$^{60}_{27}\text{Co}$ 5 μC	γ	25 mm	Nil	65
			Thick paper	60
			2 mm Al	55
			20 mm Pb	19

Demonstration 12.14. (i) Solid state detectors in general can be made to detect all three kinds of radiation but the particular one recommended is only sensitive to α particles.

(ii) Since the maximum range in air at STP is only about 6 cm no α particles will be detected. Evacuating the tube reduces the number of collisions likely to occur in each centimetre of tube; i.e. the mean free path is increased.

(iii) 'Very slightly' means just that. The end of the tube has to be raised no more than about 0.5 cm. The change in the count rate is detectable.

Demonstration 12.15. (i) One important property of the decay curve should be emphasised. Any point on the curve can be taken as the 'starting point' and it will then be found that the time taken for the activity to fall to half its value at that point is independent of the actual starting point chosen. This time is always the half-life.

(ii) In radioactive disintegration the total mass present remains very nearly constant (the change cannot be detected by weighing). The only loss is due to the ejection of α and β particles. The atoms of the radioactive substance itself are not ejected.

Experiment 12.16. This works very well, producing a good approximation to an exponential curve until the number of cubes left is too small. It is not such a good analogue as the one described in Demonstration 12.15 since one of the variables is not 'time' but the 'number of throws'.

The half-line can be calculated quite simply.

After one throw we will have $\frac{5}{6} N$ cubes left. N is the original number and we would expect one in six to fall with the black face uppermost.

After two throws we will have $\frac{5}{6} \times \frac{5}{6} N = \left(\frac{5}{6}\right)^2 N$ cubes left, and after x throws the number left will be $\left(\frac{5}{6}\right)^x N$.

The half-life is the number of throws that will leave $\frac{N}{2}$ cubes.

$$\text{So } \left(\frac{5}{6}\right)^x N = \frac{N}{2} \quad \text{i.e. } x(\log 5 - \log 6) = \log 1 - \log 2.$$

$$x = \frac{0 - 0.301}{0.699 - 0.778} = \frac{301}{79} = 3.8 \text{ throws.}$$

The half-life can be measured from any point on the curve, not necessarily from the beginning.

Demonstration 12.17. The V-shaped tracks are caused by the decay of a radon-220 atom to polonium-216, followed very quickly by the decay of this daughter product, which has a half-life of only 0.2 seconds. Both radon-220 and polonium-216 are α emitters.

Demonstration 12.18. The ionisation chamber plus d.c. amplifier technique is superior to the pulse electroscopes method on two counts. It gives a meter reading directly proportional to the activity and the overall time required to complete the experiment is much less.

One way of involving the class in the experiment is to distribute a number of stop-watches or stop-clocks and tell the operators to find the time taken for the reading to fall from (1) 1 mA to 0.5 mA, (2) 0.8 mA to 0.4 mA, (3) 0.6 mA to 0.3 mA, etc., respectively. They should find that all these times are the same.

ANSWERS TO QUESTIONS AND PROBLEMS

1. Make sure that there are no sources within at least 1 m of the Geiger tube. The period over which the background count rate is determined should not be less than 2 minutes. This background count rate is then subtracted from any subsequent measurement made with a source.

2. See pages 83 and 84 of Book Three of 'Physics is Fun'.

If we assume that the masses are equal then:

By the Law of Conservation of Momentum—

$$\begin{array}{ccc} \rightarrow & \rightarrow & \rightarrow \\ V & = & V_1 + V_2 \end{array}$$

and by assuming that Kinetic Energy is conserved—

$$\frac{1}{2}V^2 = \frac{1}{2}V_1^2 + \frac{1}{2}V_2^2$$

The first equation represents a closed vector triangle and the second shows that the triangle must be right-angled.

3. The marks at P, Q and R are made by α particles, γ rays and β particles respectively.

4. Use a detector which is insensitive to β and γ radiation, e.g. a spark counter, and ionisation chamber with a d.c. amplifier or pulse electroscopes. Verify the presence of α particles by putting a sheet of paper between source and detector and noting the large decrease in reading. The presence of β particles could be demonstrated by showing that a 2 mm sheet of aluminium will markedly reduce the count-rate as determined by a Geiger tube (the MX 168 will only count β 's and γ 's). A further 20 mm of lead is needed to materially reduce the count rate again—and only γ radiation is so penetrating.

5. Look for α rays with a spark counter; look for β and γ radiation with a G-M tube, checking each type by trying different absorbing screens between source and counter.

6. One could check by showing that no radiation from the source could penetrate a thick piece of paper.

To find out if the α particles affect the photographic plate place the source in contact with the plate with no intervening wrapper. This will have to be done in the darkroom. Wrap it all in lightproof paper and leave it for a few hours. Develop the plate and check to see whether there is a blackened area corresponding to the position of the source. There will be.

7. One could try its effect on a spark counter. This will show that there are no α particles being emitted. Furthermore one would find that practically all the radiation was stopped by 2 mm of aluminium, thus showing that no γ radiation was present.

8. The radiation would have no effect on a spark counter or an ionisation chamber, and the radiation could not be stopped by thick paper or by 2 mm of aluminium.

9. The extent to which β particles are absorbed, or 'stopped', depends on the nature and number of the atoms in the path of the particles. This will depend on both the density and the thickness of the material and manufacturers of absorbers quote the 'Stopping power' in terms of 'window weight', i.e. the product of thickness and density, usually expressed in mg/cm^2 or g/cm^2 .

Experiment will show that the β particles from strontium-90 are stopped by aluminium less than 1 mm (1,000 microns) thick. Since the density of air is so much less a much greater thickness will be needed.

Note that the actual window weight of a given material required to stop all the β particles will depend on the initial kinetic energy of these particles—and this varies from emitter to emitter. The particles which appear to come from the strontium-90 source are in fact coming from a daughter product, yttrium-91.

10. (a) An atom of an isotope of uranium disintegrates with the emission of an α particle and some γ radiation. The product is an atom of an isotope of Thorium.

(b) The thorium atom produced in (a) itself disintegrates by emitting a β particle to become an atom of a protactinium isotope.

11. The great difference in the amount by which α and β particles are deflected is not always realised. Remember that an α particle is about 8,000 times as massive as a β particle. Beta particles are easily deflected whereas alpha particles are not. γ radiation is, of course, not affected.

12. $\text{Rate} = 3.7 \times 10^9 \text{ disintegrations/second}$
 $= 0.1 \text{ curie.}$

13. $\alpha, \beta, \beta, \alpha, \alpha.$

14. Number of electrons = Z ; number of protons = Z ; number of neutrons = $(A - Z).$

- (a) Ejection of an α particle leaves an atom of mass number ($A-4$) and atomic number ($Z-2$).
- (b) Ejection of a β particle leaves an atom of mass number A and atomic number ($Z+1$).

15. It should be a γ emitter so that the radiation can easily penetrate the pipe (and possibly the earth over it) and be detected. Cobalt-60 would be a suitable isotope. The radiation could be detected by a Geiger tube and ratemeter. One would move along the line of the pipe looking for a sudden increase in the count-rate.

16. (a) 50. (b) 800.

17. P discharges an electroscope, causes sparks, its radiation is stopped by paper and is only slightly deflected by a magnetic field. P is an α emitter.

Q does not cause sparks, operates a Geiger tube; radiation will penetrate paper but not 2 mm of aluminium and it is deflected by a magnetic field. Q is a β emitter.

R does not produce sparks, nor does it cause ionisation in atmospheric air (electroscope and ionisation chamber). The radiation from it does affect a Geiger tube but is not deflected by a magnetic field. Neither paper nor aluminium will stop the radiation. R is a γ emitter.

S emits radiation that produces sparks (α particles), ionises the air, operates a Geiger tube and is partly deflected by a magnetic field. Some of the radiation will penetrate 2 mm of aluminium. S emits α , β and γ radiation.

18. γ radiation.

γ radiation intensity decreases as the inverse square of the distance from the source and is materially reduced by a few centimetres of lead, or steel. A suitable cupboard would therefore be such that the sources are kept in a compartment in the centre of the cupboard, i.e. as far away from the sides as possible, and the sides and door should be made of thick absorbing material, e.g. steel 1 cm thick. The cupboard could be in the form of a cubical box having 30 cm edges.

19. 15/16 gramme will have decayed. (After 8 days there will be $\frac{1}{2}$ g left; after another 8 days, 16 days in all, there will be $(\frac{1}{2} \times \frac{1}{2})$ g = $\frac{1}{4}$ g; after 24 days $\frac{1}{8}$ g and after 32 days $\frac{1}{16}$ g).

This quantity of matter has not disappeared. Most of it has become the mass of the daughter product. The rest is accounted for by the mass and kinetic energy of the β particles ejected.

The proton number (atomic number), Z , of the daughter product will be 54.

20. 9,600 years is $6 \times$ half-life. Therefore the mass left is $(\frac{1}{2})^6$ times the original mass, i.e. $1/64$ th of the original mass.

The total mass will be very, very nearly equal to the original mass. Any difference, which will be undetectable by weighing, can be

accounted for in terms of the mass of the α and β particles radiated together with the energy of the radiation (α , β and γ).

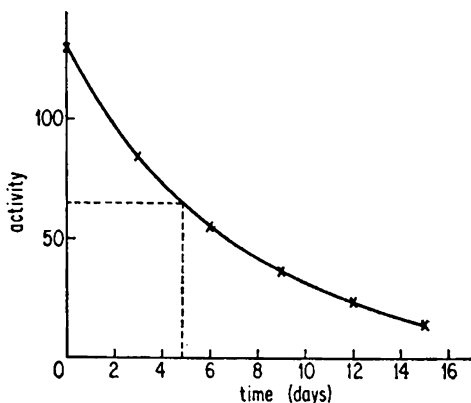
21. 10 hours is five half-lives. Hence $1/32$ nd of the original mass will be left and the activity of this mass will be $1/32$ of the original activity. This is approximately 3% of the original activity.

22. 1 mg of radium contains $\frac{6 \times 10^{23}}{226 \times 1,000}$ atoms.

Half of these will disintegrate in 1,620 years.

So the number that disintegrate = $\frac{3 \times 10^{20}}{226}$
 $= 1.33 \times 10^{18}$.

23. A carefully drawn graph will give just under 5 days as the half-life, e.g. by finding the time taken for the activity to fall from say 100 to 50, 90 to 45, 80 to 40, etc., and taking the average of these times.



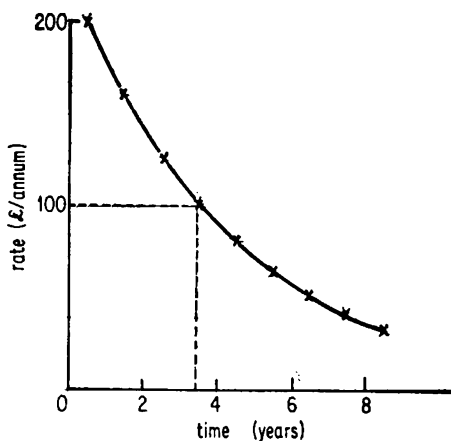
The activity of a radionuclide follows an exponential decay curve of the form $A_T = A_0 e^{-\lambda t}$, where A_T and A_0 are the activities after time T and the original activity respectively. λ is a constant, called the 'transformation constant'.

Substituting any of the given pairs of values for activity and time will yield a value of $\lambda = 0.14$.

After a time equal to the half-life the equation reduces to: $1 = 2e^{-0.14 t}$ and this yields a value for t (the half-life) of 4.9 days.

24. During each year his debt will decrease by one-fifth of what it was at the beginning of that year. The capital sums remaining at the ends of successive years will be £800, £640, £512, £410, £328, £262, £210, etc. So that the rate of repayment during the first year will be £200 per annum; during the second year £160 per annum; and in subsequent successive years £128, £102, £82, £66 per annum. The graph below shows that the rate will have dropped to half its original value during the fourth year. The curve is an exponential

one since the rate depends on the size of the loan at any time—just as the activity of a source depends on the quantity of the original radionuclide still remaining.



25. The folded blanket could be passed on a conveyor belt over, or under, a suitable container of the radioactive material. The operator would have to be adequately shielded and his position monitored to be certain that he did not receive a dangerous dose of radiation.

Such a procedure would be quicker than steam sterilisation, no drying would be needed and the blankets would not 'felt'.

26. The amount by which the paper darkens on developing it is a measure of the total radiation dose received.

The essential precautions are:

- (i) No eating, drinking or smoking is permitted.
- (ii) A laboratory coat must be worn.
- (iii) Sources must be handled with the tools provided. They must never be allowed to come in contact with the skin. They must never be held close to the eyes to examine them.
- (iv) All sources not in use must be kept in a locked drawer or cupboard.
- (v) Containers of all radioactive sources (including sealed sources) must be clearly labelled.

There are further precautions which must be taken when working with unsealed sources but the five given above refer to all work with radioactive material.

27. The daughter nucleus will have the same mass number.

It will not be another isotope of phosphorus as its atomic number will go down by one. It will be an isotope of silicon, $^{30}_{14}\text{Si}$.

28. (a) Atomic weight is the weight of an atom of a nuclide relative to the weight of an atom of carbon-12, which is taken to have an atomic weight of 12.

Atomic number is the number of protons in the nucleus.

- (b) Isotopes of an element all have the same atomic number but have different mass numbers.

A nuclide is a particular kind of atom specified by both its mass number and its atomic number.

- (c) Artificial radionuclides do not occur naturally but are made by bombarding stable nuclei with neutrons or other particles.

- (d) Atomic mass is the actual mass of an atom in kilogrammes, whereas mass number is the number of nucleons (protons + neutrons) in the nucleus.

- (e) An α particle consists of 2 neutrons and 2 protons and is identical with the helium nucleus (2 p + 2 n).

β particles are electrons ejected from the nuclei of radioactive elements.

- (f) They have equal masses but are oppositely charged—the positron being positive.

29. (a) Mass difference = $(16,749 + 9 - 16,726) \times 10^{-31}$
 $= 32 \times 10^{-31}$ kg.

This is equivalent to an energy change of

$$\begin{aligned} & 32 \times 10^{-31} \times 9 \times 10^{16} \\ &= 288 \times 10^{-15} \\ &= 2.88 \times 10^{-13} \text{ J.} \end{aligned}$$

Energy is absorbed in this reaction and converted into mass.

- (b) Mass difference = $(16,749 - 16,726 - 9) \times 10^{-31}$
 $= 14 \times 10^{-31}$ kg

$$\begin{aligned} \text{Energy change} &= 14 \times 10^{-31} \times 9 \times 10^{16} \\ &= 126 \times 10^{-15} \\ &= 1.26 \times 10^{-13} \text{ J.} \end{aligned}$$

Energy is evolved in this reaction.

30. Power = Rate of gain of energy
 $= \text{Energy gain of each proton} \times \text{number of protons per second}$
 $= 7 \times 10^9 \times 1.6 \times 10^{-19} \times 10^{11}$
 $= 7 \times 1.6 \times 10$
 $= 112 \text{ W.}$

13 Quack, Quanta, Quark (pp. 209–239)

As is made clear in the preface to Book Four this chapter is really an 'Optional Extra'. It could be a reading exercise for the abler and keener pupils and should help to counteract any false notions that 'science' knows all the answers. It provides a picture of the developing nature of physics research in the field of atomic and nuclear physics and emphasises its continuing nature.

ANSWERS TO QUESTIONS AND PROBLEMS

1. There will be some debate as to what are the basic principles covered in this course. The following are suggestions of the sort of answers we may expect to receive from our pupils at this stage.

(i) Matter is made up of separate particles—atoms and molecules.

(ii) The atoms themselves are built up of neutrons, protons and electrons. The arrangement of these fundamental particles determines the chemical and physical properties of a particular atom.

(iii) Linear momentum, mass/energy and electric charge are conserved in any interaction.

(iv) Mass and energy are interconvertible, i.e. they are different manifestations of the same fundamental entity.

(v) There are various kinds of forces—electromagnetic, gravitational and nuclear—operating between the fundamental particles.

2. The gain in mass = 0.00218×10^{-27} kg = 2.18×10^{-30} kg.

3. Energy lost = $2.18 \times 10^{-30} \times 9 \times 10^{16}$ (c = 3×10^8 m/s)
= 1.962×10^{-13} J.

4. Before the reaction.

Total mass = 13.3235×10^{-27} kg
= 119.9115×10^{-11} J.

Energy = 0.5 MeV = 0.008×10^{-11} J.

Total mass/energy = 119.9195×10^{-11} J.

After the reaction.

Total mass = 13.29264×10^{-27} kg
= $119.63376 \times 10^{-11}$ J.

Energy = 17.2 MeV = 0.2752×10^{-11} J.

Total mass/energy = $119.90896 \times 10^{-11}$ J.

Taking a reasonable number of significant figures, the mass + energy is the same on both sides of the equation.

